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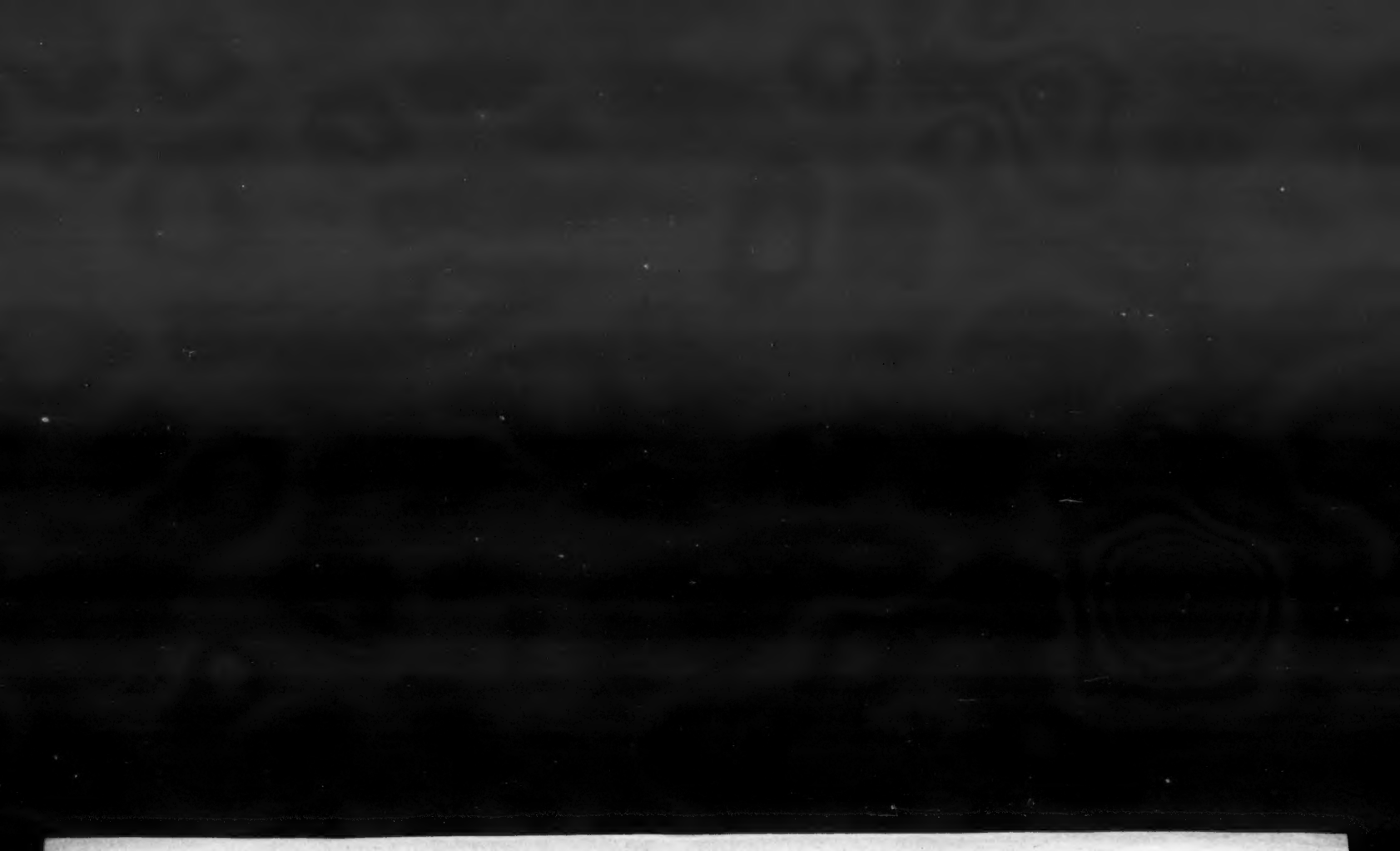

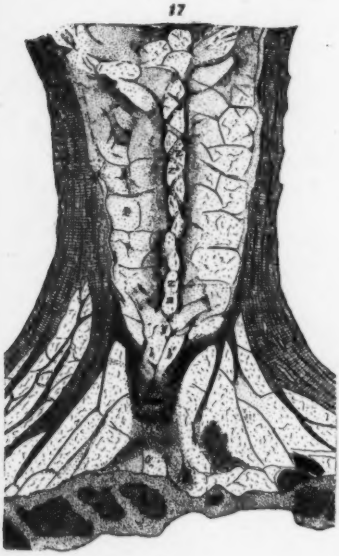
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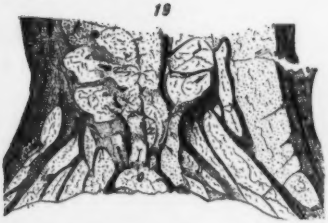
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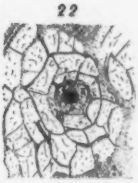
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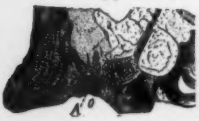
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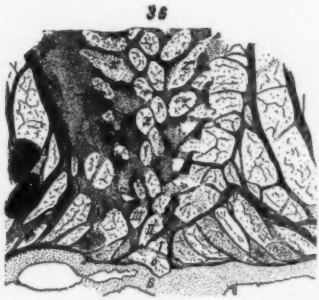
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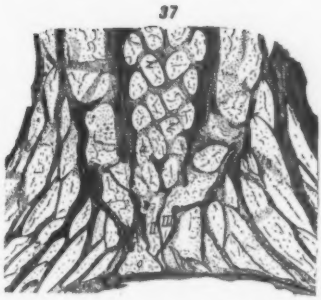
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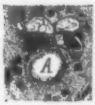
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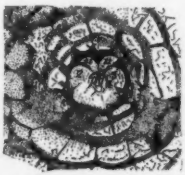
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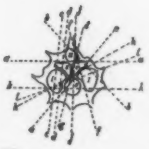
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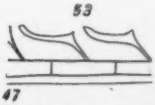
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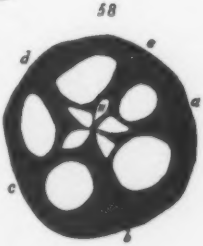
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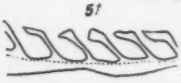
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THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XX. — *Development of Fenestella*; by EDGAR ROSCOE CUMINGS, Ph.D. (With Plates V, VI, and VII.)

Introduction.

DURING the past two years, the writer's studies of the development of Paleozoic Bryozoa* have brought out some very interesting points bearing upon the earliest stages of *Fenestella*. The present paper deals with the development (astogeny) and morphology of *Fenestella*, and is based entirely upon calcified material from the Hamilton formation of Thedford, Ontario.† This material consists of numerous bases of *Fenestella* colonies. In these, the minutest details of internal structure are preserved with remarkable fidelity. The method of study has been the preparation of both thin and serial sections. The latter were obtained by slowly grinding down the bases and accurately drawing each stage as seen by reflected or in some cases by transmitted light. The specimens studied are in various stages of growth. Some represent the bases of adult colonies from which the adult (ephebastic) portion has been lost; others are minute bases, which in their growth never proceeded farther than the nepiastic stage. In these nepiastic

* In a former paper, a classification of the growth stages of the bryozoan colony was given, together with a general classification of the growth stages of any colony belonging to any group of organisms. The terms applicable to the growth stages of any colony are: *Nepiastic*, *neanastic*, *ephebastic*, and *gerontastic*, corresponding to the well-known terms *nepionic*, *neanic*, *ephebic*, and *gerontic*, applicable to the growth stages of the individual. Dr. Ruedemann has recently proposed the term *astogenetic* with reference to the colony, as the term parallel with *ontogenetic* with reference to the individual. The *astogenetic* stage of a colony, therefore, corresponds with the *ontogenetic* stage of an individual.

† This *Fenestella* is probably the form listed by Grabau as *Semicoscinium labiatum*.

colonies, the zoœcia emerge upon the surface; but in the older ones, the apertures of the zoœcia in the basal portion are submerged in a copious deposit of punctate sclerenchyma. In all cases, however, there has been no resorption of the earlier zoœcia, so that sections of the bases of ephebastic or gerontastic zoaria reveal the morphology of the earliest stages as faithfully as sections of a nepiastic colony. As an aid to the elucidation of the astogeny of *Fenestella*, the writer studied the astogeny of *Retepora phœnicea*, a recent bryozoan morphologically very similar to the ancient Fenestellas and Polyporas.

In the writer's former paper on the development of Paleozoic Bryozoa, the term *protœcium* was introduced as designating the primary individual of the colony. In this sense, it would have the same signification as the term *ancestrula* of Jullien or *primary cell* of Hincks. In the Cyclostomata, as is well known, the first zoœcium surmounts a hemispherical base (*basal disc*), which serves as the point of attachment of the young colony to the substratum. This basal disc has been shown to be the calcified wall of the metamorphosed and histolyzed embryo (Barrois and others). It is believed by the present writer that the persistence of this structure (kathembryonic stage) in the ancient order of Cyclostomata is not without significance, especially in view of the fact, to be shown presently, that it is a conspicuous feature in the development of the ancient Cryptostomata and possibly of the Trepostomata (*Phylloporina corticosa*). The basal disc is probably the *true* first zoœcium. In the present paper, therefore, the term *protœcium* is restricted to the basal disc or its equivalent, and the superjacent portion of the primary cell is designated the *ancestrula*. In many recent Chilostomata, there seems to be no distinction of protœcium and ancestrula. This may mean that the extreme acceleration of these modern types has practically eliminated the protœcium from the ontogeny. In the ancient Cryptostomata, on the other hand, the protœcium greatly predominates over the ancestrula, which is often little more than an exaggerated aperture to the former. In any case, the ontogenetic stage of which the protœcium is the index is always present throughout the Ectoprocta, for by a degenerative metamorphosis they all give rise to a hemispherical kathembryo, from which the adult polypide arises by a sort of budding process. Furthermore, this kathembryo becomes invested with a calcareous or chitinous ectocyst, which is the first skeletal structure of the developing individual. The protœcium is therefore very closely analogous to the protegulum of brachiopods, the protoconch of cephalopods, etc.

Development of Fenestella.

The Protœcium.

Many well-preserved *Fenestella* bases show a minute circular pit on their basal surface. This can be seen only in colonies that were attached to a substratum which disappeared in the process of fossilization, leaving the basal surface of the colony free from all extraneous matter. Where the colony is still attached to the substratum, frequently the frond of another bryozoan, the circular pit can always be demonstrated by means of thin sections. This pit is the protœcium. As will be seen from the longitudinal sections (figs. 20, 36, 37, 59), the protœcium is separated from the substratum by a thin basal membrane. In such sections, this pit appears as a semicircular object in the proximal portion of the colony. In transverse sections, it appears as a dark ring surrounded by concentric zones of punctate secondary sclerenchyma. That the protœcium has its own proper wall, similar to that of ordinary zoœcia, is shown by numerous sections (figs. 36–38, and 59). The diameter of the protœcium is from 0·4—0·6^{mm}, or about three or four times that of the ordinary zoœcia. In form and position it corresponds precisely to the basal disc of Cyclostomata, and there can be little doubt that it has the same morphological and developmental significance.

The Ancestrula.

The protœcium is surmounted by a tubular structure arising from the center of its distal surface. This is the ancestrula. In some of the earlier sections prepared by the writer, one of the primary buds was mistaken for the ancestrula, and its size and shape were therefore thought to be different from what was shown in later sections. It is considerably smaller than the primary buds, being both shorter and of less diameter. It seems altogether likely that the primary polypide never permanently ascended into the ancestrula as in the Cyclostomata. On the other hand, the ancestrula of *Fenestella* is far from being the homologue of the vestibule of ephebastic zoœcia. It is not built up of secondary deposits, but is composed of the same thin non-punctate substance as the proper wall of the protœcium and other zoœcia. The homology of the ancestrula of *Fenestella* is with the tubular primary zoœcium of the Cyclostomata. Figures 59 and 60 indicate the shape and appearance of the ancestrula as seen in the majority of properly orientated longitudinal sections,* and figures 10–13, 24, 43, and 54 in transverse sections.

* The zoœcium marked *I*, in figures 19 and 20, was at first thought to be the ancestrula, since it communicates freely with the protœcium. A careful study of the appearances possible in a series of longitudinal sections with

The Primary Buds.

Two lateral primary buds arise from the primary zoœcium (figs. 3–7, 21–23, 40–43). There is still some question as to whether these buds arise from the protœcium or from the ancestrula. The sections figured reveal all that can be expected. The question becomes one of interpretation and of analogy with recent Bryozoa. The proximal ends of the primary buds are in contact with the protœcium and are separated from its cavity by a very thin calcareous wall, which is frequently broken away (figs. 19 and 20). The appearance of this wall is well shown in figure 36. Figures 3–7 and 38–40, 42 show the intimate relation of the primary buds to the protœcium. From the analogy of recent Bryozoa, on the other hand, these buds might be expected to originate from the ancestrula. A median primary bud is not indicated by any of the sections. If it existed, it certainly arose from the ancestrula.

The size, shape, and position of the primary buds is beautifully shown in figures 38 and 39, and in the transverse sections. These buds are long and tubular, and diverge but slightly from the axis of the zoarium. There is no long vestibule as in ephebastic zoœcia, but the whole aspect of the buds is that of a simple tubular zoœcium, quite similar to that of the Cyclostomata. There is also no indication of hemisepta or any other structures within the zoœcium.

Secondary Buds.

All buds of the second generation from the protœcium are designated secondary buds. The series of sections (figs. 1–16) seems to indicate that each of the primary buds produces a lateral and a median bud. The lateral buds are very clearly shown in such a position that they could have originated from no other source than from the primary buds (see especially figs. 5, 41, and 42). The median buds belong to the second tier of zoœcia. They are designated II_2 and II_3 in figure 13. The shape of the secondary buds is quite similar to that of the primary ones (figs. 37, 45, 59, and 60). Figure 50 is a drawing

different assumed orientation has convinced the writer that the zoœcium in question is a primary bud. To test this, four different bases in which the protœcium and primary buds could be seen on the basal surface (in some cases only after slight etching) were sectioned in the direction $j - j$, figure 48, which had been determined by previous inspection of the basal surface, and marked by carefully drawing a fine line through the center of the protœcium and as nearly as possible between the primary buds. Every one of these sections has the appearance shown in figures 59, 60, and 45. It is therefore unlikely that figures 19 and 20 (which were orientated at random) represent the ancestrula. It is needless to state that only a very small proportion of the many sections prepared in this study are figured.

of a secondary bud, and may be compared with figure 53, which is a drawing of two zoœcia of *Protocrisina* (after Ulrich), a cyclostomatous bryozoan from the Trenton. The resemblance is too striking to need further emphasis. No internal zoœcial structures have been observed in the secondary buds.

Tertiary and Later Buds.

One bud of the third generation from the ancestrula occupies a position in the first tier of zoœcia, diametrically opposite the ancestrula (*III*, figs. 6–13, 24, 26, 43, 54–58). The shape of this bud is well shown in figures 37, 45, 59, and 60. There is no means of telling from which of the two secondary buds this tertiary one is derived. It may have originated now from one, now from the other. In figure 43, it is rather more intimately associated with *32*, which was in turn derived from the right lateral primary bud. Figure 13 indicates that each of the secondary buds gives rise to a median bud lying in the second tier of zoœcia.

Ascending the axis of the zoarium (figs. 17–20, 36–39), there is exhibited a series of zoœcia very symmetrically arranged about the axis. In transverse sections, above the level of *y*, figure 17, these present a peculiar star-shaped appearance seen in figures 15, 16, and 58, as well as in figure 61 of the writer's former paper. The order of budding of these later zoœcia cannot be determined, although the writer has devoted a large amount of time and study to this point. It is probable that the order of budding in these later generations is without significance. An important point shown by the sections, however, is the shape and size of these zoœcia. This is best seen in figures 17 and 38. The zoœcia are tubular, but somewhat less elongate than the earlier ones. It is not until the zoarium begins to expand into its characteristic infundibular form that the zoœcia assume the shape normal to *Fenestella*. Figure 51 shows a row of zoœcia from the neanastic region (base of the cone) of the specimen represented in figure 38. For comparison with this is inserted figure 52, showing a specimen of *Fenestella acmea* from the Waldron shale of Tarr Hole, Indiana. The resemblance is striking. The adult zoœcia of the Thedford *Fenestella* are shown in figure 49.

Discussion and Conclusions.

The morphological element of the bryozoan colony which corresponds to the primitive integument of Mollusca, Brachiopoda, etc. (that is, to the protoconch, protegulum, etc.), is the *protœcium*, or basal disc, of the primary individual of the colony. The protœcium is the calcareous or chitinous wall of

the kathembryo. In *Fenestella* it is very large and in every way similar to the protœcium (basal disc) of the Cyclostomata. The ancestrula is the tubular superstructure of the primary individual. It is a simple, undifferentiated, tubular zoœcium. The earlier formed zoœcia (nepiastic zoœcia) of the *Fenestella* colony differ markedly in shape and size from later formed (neanastic and ephebastic) zoœcia. In every feature in which they depart from the ephebastic zoœcia of *Fenestella* they approach the ephebastic zoœcia of the Cyclostomata.

From these observations, it may be reasonably concluded that *Fenestella* as well as the entire order of Cryptostomata is derived from the Cyclostomata. Certain other general conclusions, more or less speculative, are suggested by a consideration of the probable significance of the protœcium and ancestrula.

The meaning of the degenerative metamorphosis of Bryozoa has always been a puzzle to students of this class. The striking analogy of this metamorphosis to the degeneration of an ordinary polypide and production of a brown body, together with the nearly identical life history of the regenerating polypide or of ordinary buds and the primitive polypide issuing from the kathembryo, have more than once led to the suggestion that the primitive polypide is in the true sense a bud. The writer is inclined to hold this view. Assuming, therefore, that the primitive polypide is a bud, the following suggestions may be made in regard to the significance of the metamorphosis and of the resulting protœcium:

1. In the primitive bryozoan, there was no histolysis of the larval organs. The development was direct and resulted in a primitive zoœcium and polypide.

2. This primitive zoœcium was hemispherical in shape and possessed a simple aperture in the center of its upper surface. Some ancient types of Cyclostomata retain nearly such a form of zoœcium (*Stomatopora* of the Trenton, especially *S. turgida*).

3. This primitive zoœcium might now give rise to a linear adnate series of zoœcia, as in *Stomatopora*, or to a series of superposed zoœcia, as in the Trepostomata. By variations of zoarial habit based upon one or the other of these fundamental plans of budding all existing types of Bryozoa could have been produced.

4. In accordance with the law of tachygenesis, later in the history of the bryozoan group a tendency toward concentration of the early stages in development would arise. In any colony the tendency to degenerate may be supposed to have applied to the primitive polypide as well as to later ones, and finally to have become an invariable part of its life history. By the continued operation of the law of tachygenesis, the life history of the first polypide became so abbreviated as to be

represented only by its degenerative stage, that is, by its latest growth stage, all the earlier growth stages having been crowded out or back into the larval stage.

In accordance with this interpretation of bryozoan development, the large size of the protœcium in ancient types is explicable and is thought to be due to a less degree of acceleration, the calcification of the zoœcial wall of the primitive individual being allowed to proceed nearly to completion before the second zoœcium was superposed upon it. The probability that the first polypide remains in the protœcium in *Fenestella*, instead of ascending into the ancestrula as in modern Cyclostomata, may indicate a still more primitive condition. The relations of the protœcium and ancestrula in the Cyclostomata and in *Fenestella* suggest the normal relation of superposition of the zoœcia in the Trepostomata. It is not without interest to find evidence, in the development of Paleozoic Bryozoa, of the fundamental relationship of these great groups. Ulrich (Geol. Surv. Illinois, vol. viii) has already suggested such a relationship on the ground of the resemblances of such types as the early Fenestellas, *Phylloporina* and *Protocrisina*. The evidence presented by these adult types is greatly strengthened by the striking parallelism of the nepiastic stages of *Fenestella* with the series of adult types named above.

Paleontological Laboratory, Indiana University,
June, 1905.

EXPLANATION OF PLATES.

*Description of Figures.**

Letters having the same meaning for all the figures:—

a, *b*, *c*, *d*, *e*, primary carinæ (except figs. 17, 24, 47, and 48).
f, fenestrule.
k, carina.
o, protœcium.
s, substratum of bryozoan colony.
z, *z'*, etc., zoœcia of generations later than the primary zoœcia.
A, ancestrula.
I, primary bud.
II, bud of second generation, that is, derived from a primary bud.
III, bud of third generation.
2, left lateral bud.
3, right lateral bud.
23, right lateral bud of the second generation, derived from a left lateral primary bud.
32, left lateral bud of the second generation, derived from a right lateral primary bud.

* All drawings except figures 1–16 were made with the camera lucida. Figures 30–32 are after Barrois, and figure 53 is after Ulrich. All the specimens of *Fenestella* are from Thedford, Ontario.

PLATE V.

FIGURES 1–16.—Transverse serial sections of a *Fenestella* base. These sixteen sections represent 1^{mm} thickness of rock.

FIGURES 1, 2.—Protœcium (cf. figs. 40, 41, 31–35).

FIGURE 3.—Section in the plane of *a*–*a*, figure 47, cutting the proximal ends of the primary buds and the buds of the second generation (secondary buds) (cf. fig. 42).

FIGURES 4, 5.—Successively higher sections.

FIGURE 6.—Section in plane of *a*′–*a*′, figure 47, cutting the proximal end of the tertiary bud (cf. fig. 43).

FIGURES 7–12.—Successively higher sections between the planes of *a*′–*a*′ and *c*–*c*, figure 47, showing the development of the initial buds. Figures 10–12 cut the aperture of the ancestrula (cf. fig. 24, with fig. 12).

FIGURE 13.—Section cutting the proximal ends of buds of the second tier (*II*$_{21}$, *II*$_{31}$, *IIIb*, and *IIIc*) (cf. fig. 26).

FIGURE 14.—Section just cutting the distal end of the aperture of the ancestrula.

FIGURES 15, 16.—Assumption of the star-shaped arrangement of zoœcia, characteristic of the paranepiastic stage of *Fenestella*.

PLATE VI.

FIGURE 17.—Longitudinal section of a *Fenestella* base cutting in the plane of *e*–*e*, figure 47, and *a*–*a*, figure 48. This section passes through the edge of the protœcium and misses the ancestrula entirely. *b*, *b*′, buds of the second tier. At *z* and *z*′ the zoœcia are vertically above each other; at *z*″, *z*‴ they alternate, and at the top of the figure they lie side by side. ×17.

FIGURE 18.—Longitudinal section cutting still more excentrically than that shown in figure 17, probably in the plane of *b*–*b*, figure 48. This misses the protœcium and ancestrula entirely, but their relative position is shown at *o* and *A*. The vertical alignment of zoœcia is shown at *z*–*z*′ and the ordinary arrangement, on either side of the carina, at *z*″. The bifurcation of a primary branch is shown at *g*–*h* (between *z*″ and *g*, *h*). In each new branch, the zoœcia first alternate and later lie side by side. Normal arrangement shown at *k*′ *k*″. ×17.

FIGURE 19.—Longitudinal section cutting in the plane of *c*–*c*, figure 48. The section cuts a row of zoœcia (*z*′–*z*″) nearly longitudinally. ×17.

FIGURE 20.—Section in nearly the same plane as in figure 19 (*d*–*d*, figure 48). This section was orientated by polishing and etching the basal surface of the colony and marking the position of the protœcium and primary buds. The section was then ground as nearly as possible in the marked direction. A primary bud is very clearly shown (*I*). ×17.

FIGURE 21.—Transverse section in the plane of *a*–*a*, figure 47. The primary buds are very distinct. ×17.

FIGURE 22.—Similar section of another specimen, cutting the proximal end of the ancestrula. ×17.

FIGURE 23.—Transverse section of a very slender base. Section in about the same plane as 22. ×17.

FIGURE 24.—Section in the plane of *b*–*b*, figure 47. Ancestrula very distinct. ×17.

FIGURE 25.—Longitudinal section of a base from which the substratum was absent. ×17.

FIGURE 26.—Transverse section in the plane of *d*–*d*, figure 47, showing the proximal ends of two buds of the second tier (*z*, *z*′) (cf. fig. 13). ×17.

FIGURE 27.—Protœcium and ancestrula of *Retepora phœnicea* from St. Vincent's Gulf, Australia. ×27.

FIGURE 28.—Ancestrula and three primary buds (*1*, *2*, *3*) of *Retepora phœnicea*. ×29.

FIGURE 29.—Profile view of protœcium and ancestrula of another specimen of *Retepora phœnicea*. ×27.

FIGURE 30.—Protœcium, ancestrula, and primary bud of *Tubulipora*. After Barrois. ×27.
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FIGURE 32.—Ancestrula and primary bud of *Schizoporella*. ×33.
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PLATE VII.

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FIGURES 54–58.—Serial sections of a *Fenestella* base. Same specimen as that shown in figure 42, figure 54 being the next section above. Figures 55–58 are successively higher sections. ×17.
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FIGURE 60.—Semidiagrammatic drawing from figure 59.

Art. XXI.—*Age of the Monument Creek Formation;** by N. H. Darton.

This contribution is an account of additional evidence as to the Oligocene age of the Monument Creek formation, or at least of its upper member, afforded by the discovery of Titanotherium and other fossil bones at several localities.

On the high divide between the Platte and Arkansas drainage basins, at the foot of the Rocky Mountains, there is an extensive deposit of sands, gravel and clay to which F. V. Hayden gave the name of Monument Creek group.† This observer recognized the fact that the group overlies the Laramie formation unconformably, but apparently he included in its lower portion more or less of the beds later separated, as the Arapahoe and Denver formations in the Denver region. The opinion was held that it was of early Tertiary age, but no precise correlation was suggested. In 1873, Prof. E. D. Cope examined a portion of the deposit and found a few bones in regard to which he made the following statement:‡

"The age of the Monument Creek formation in relation to the other Tertiaries not having been definitely determined, I sought for vertebrate fossils. The most characteristic one which I procured was the hind leg and foot of an *Artiodactyle* of the Oreodon type, which indicated conclusively that the formation is newer than the Eocene. From the same neighborhood and stratum, as I have every reason for believing, the fragment of the *Megaceratops coloradoensis* was obtained. This fossil is equally conclusive against the Pliocene age of the formation, so that it may be referred to the Miocene until further discoveries enable us to be more exact."

Doubtless Professor Cope regarded the fauna as belonging in the White River group, which is now generally considered to be Oligocene. He added nothing regarding the precise locality, or stratigraphic position of the fossils. So far as I can find, no further paleontological evidence has since been offered, regarding the age of the formation. A brief account of the Monument Creek formation was given by G. H. Eldridge, in the "Geology of the Denver Basin."§ The true stratigraphic limits of the formation in relation to the underlying

* Published by permission of the Director of the United States Geological Survey.

† Preliminary field report of U. S. Geological Survey of Colorado and New Mexico, 1869, p. 40.

‡ [7] Annual Report of the United States Geological and Geographical Survey of the Territories, embracing Colorado, Report for 1873, by F. V. Hayden, p. 430.

§ United States Geological Survey, Monographs, vol. xxvii, pp. 252–254.

Laramie, Arapahoe and Denver formations were recognized, and it was shown that the formation consists of two distinct members separated by a well-defined break in deposition. The lower member lies on an uneven floor of Denver formation at the north and Laramie to the southeast. It displays "marked regularity in the succession of its beds, excepting at the base, where, owing to the uneven floor, the material varies from conglomerate through sandstone to arenaceous shale. A short distance above the base are two broad bands of green shale separated by one of pink and capped by a fine grit, or sandstone, which is soft and friable and easily disintegrates." The thickness is estimated to be about 900 feet. The sandstones and grits of the lower member are mostly of granite debris. The upper member consists of sandstones and shales, with numerous beds of conglomerate, and between the two there are local deposits of rhyolitic tuff, in places 40 feet thick, which are quarried extensively for building stone near Castle Rock. In the lower part of the upper member many fragments of this rhyolitic tuff occur, a feature which is notably displayed in the breccia and conglomerate capping the butte known as Castle Rock. The thickness of the upper member is estimated by Eldridge at about 400 feet. In portions of the area, I have observed that in the lower member there are extensive deposits of massive clay, very similar in appearance and properties to the fullers earth which is characteristic of the Chadron formation, or Titanotherium beds, of the White River group in the Big Bad Lands of South Dakota and elsewhere.

In the general résumé of the geology in the Monograph on the Denver Basin,* Mr. Emmons suggests that the vertebrate remains of Miocene age probably were from the lower member of the formation and that the upper member might be correlated with the Pliocene. This suggestion was based on the fact that the uppermost Tertiary deposits in the eastern portion of Colorado are of Pliocene age, and in the region north of the Platte River they lie unconformably on White River beds. Mr. Emmons recognized the fact that these beds differ somewhat from Monument Creek beds in character, yet this could be explained by the proximity of the Monument Creek formation to shore lines along the mountain front.

Two years ago, while examining the southern portion of the Monument Creek area, I obtained from the conglomerate four miles northwest of Calhan, the distal end of a large humerus which Dr. F. A. Lucas has identified as Titanotherium. This conglomerate is the upper member of the formation and caps a long line of buttes and extensive plateaus. A number of

* Loc. cit., p. 39.

bones have also been collected for me along the valley of Cherry Creek, half way between Castle Rock and Elizabeth, consisting mainly of bones of titanotherium. They were obtained at many localities and all from the sandstones of the upper member of the formation. A fragment of a lower jaw of titanotherium was the most distinctive fossil obtained. It was found in the upper beds, at Kaumpfer's ranch, 7 miles southwest of Elizabeth. In Wild Cat Canyon, 6 miles west-by-south of Elizabeth, were found fragments of a jaw and the distal ends of a titanotherium tibia and humerus. Portions of a lower jaw of hyracodon, apparently *nebrasensis*, were found in a well at Anderson's place 6 miles south-southwest of Elizabeth, together with various turtle bones. All of this material appears to have been obtained from the upper beds and it correlates these beds with the Chadron formation of the White River group, or Oligocene. No evidence was obtained as to the age of the lower member, but the fullers earth, as before mentioned, is similar to that which is so characteristic in other areas. The presence of the unconformity between the upper and lower members suggests that the latter may be of Wasatch or Bridger age. The nearest locality to the Monument Creek area, at which Oligocene deposits occur in eastern Colorado, is in the vicinity of Akron and Fremont's Butte, where titanotherium remains occur in abundance. Farther north, in the region about Pawnee Buttes, there are well-known localities of the titanotherium and overlying beds. In the low intervening area, east and southeast of Denver, Oligocene deposits are absent, but it is probable that originally they extended continously from the vicinity of Akron to the foot of the Rocky Mountains in the Monument Creek area. There is much evidence throughout the Great Plains region that the Oligocene deposits were originally of wide extent, for outliers occur along the mountain slopes and in many widely separated areas. They have been subjected to extensive degradation in Miocene, Pliocene and later times and probably removed from large districts, especially in the wider valleys. In my recent report on the Great Plains,* there is given a map showing their present distribution and probably former great extent.

* United States Geological Survey, Professional Paper No. 32, pl. xliv.

ART. XXII.—*The Iodometric Determination of Aluminium in Aluminium Chloride and Aluminium Sulphate;* by S. E. MOODY.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—cxxxviii.]

A PROCESS for the gravimetric determination of alumina in salts of aluminium has been described by Stock,* who bases the method upon the reaction represented by the following equation:

$$Al_2(SO_4)_3 + 5KI + KIO_3 + 3H_2O = 2Al(OH)_3 + 3K_2SO_4 + 6I$$

This equation would show that iodine is liberated when potassium iodate and potassium iodide are together added to a solution of aluminium sulphate. It was found, however, that in the action of the iodide-iodate mixture upon a solution of potassium alum, only about two-thirds of the iodine corresponding to the aluminium salt is accounted for; and this suggests that the reaction is not completed according to the equation, and that the precipitate formed is not the simple hydroxide. Upon ignition the precipitate yields, however, the total amount of alumina present; and, since the character of the precipitate is good, the process is easily managed and gives, as Stock has said, an excellent gravimetric method for the determination of alumina.

Taking aluminium chloride, $AlCl_3 . 6H_2O$, and proceeding in the same manner, similar results are obtained, and after dissolving the precipitate in sulphuric acid and adding silver nitrate to the dilute solution, a decided precipitate of silver chloride is observed, which upon washing, drying and weighing is found to be about one-third of the amount of that substance corresponding to the original aluminium chloride. This indicates that it is an oxychloride which is formed on the addition of potassium iodide and iodate; moreover, upon removing by sodium thiosulphate the iodine first set free in the action and allowing the mixture to stand, progressive hydrolysis takes place as shown by the return of color due to iodine, and this change can be still further hastened by heating after adding an excess of sodium thiosulphate to take up the iodine as liberated. The attempt was made, therefore, to complete the reaction between the iodide-iodate mixture and the aluminium chloride, or alum, by heating the solution in a Voit flask through which steam or, still better, hydrogen was passed, as an aid in the transfer of the iodine liberated to a receiver

* Ber. Dtsch. Chem. Ges., 1900, xxxiii, i, p. 548.

charged with a solution of potassium iodide. The iodine collected was titrated with $\frac{n}{10}$ sodium thiosulphate.

Table I gives results obtained by this method. The details of the experiments in which steam was used as an agent to force the iodine over are given in section A, while those of the experiments in which hydrogen was employed are indicated in section B.

TABLE I.

Approx. $\frac{n}{10}$ Aluminium chloride solution. cm^3.	HIO_3. grm.	KI. grm.	Time in minutes.	Approx. $\frac{n}{10}$ $Na_2S_2O_3$. cm^3.	Al_2O_3 calculated grm.	Diff. grm.
			A			
25	0·3	1·0	25	25·05	0·0427	−0·0007
25	0·3	1·0	90	25·15	0·0428	−0·0006
			B			
25	0·3	1·0	20	25·05	0·0427	−0·0007
25	0·3	1·0	15	25·10	0·0428	−0·0006
25	0·3	1·0	15	25·00*	0·0426	−0·0009
25	0·3	1·0	15	25·00*	0·0426	−0·0009

In each of these experiments the iodide-iodate mixture was made by exactly neutralizing iodic acid with potassium hydroxide, adding a minute crystal of the iodic acid, introducing the potassium iodide in solution and taking up with a drop or two of sodium thiosulphate the iodine set free. This mixture was put into the Voit flask together with the aluminium chloride, and the whole was heated in the current of steam or hydrogen.

Applying the process to a solution of potassium alum the results recorded in the following table were obtained.

TABLE II.

Approx. $\frac{n}{10}$ Aluminium potassium alum. cm^3.	KIO_3. grm.	KI grm.	Time in minutes.	Approx. $\frac{n}{10}$ $Na_2S_2O_3$. cm^3.	Al_2O_3 calculated. grm.	Al_2O_3 found. grm.	Diff. grm.
25	0·3	1·0	30	24·55	0·0410	0·0414	−0·0004
25	0·3	1·0	30	24·60	0·0411	0·0416	−0·0005
25	0·3	1·0	25	24·50	0·0409	0·0414	−0·0005
25	0·3	1·0	30	24·70	0·0413	0·0416	−0·0003
25	0·3	1·0	35	24·50	0·0409	0·0415	−0·0006
25	0·3	1·0	30	24·55	0·0410	0·0415	−0·0005
25	0·3	1·0	25	24·50	0·0409	0·0415	−0·0006

*New standard.

In Table III are shown results of the application of the process to an ammonium alum.

TABLE III.

Approx. $\frac{n}{10}$ Ammonium alum. cm^3.	KIO_3. grm.	KI. grm.	Time in minutes.	Approx. $\frac{n}{10}$ $Na_2S_2O_3$. cm^3.	Al_2O_3 calculated grm.	Diff. grm.
25	0·3	1·0	20	25·20	0·0429	+0·0007
25	0·3	1·0	15	25·17	0·0429	+0·0007
25	0·3	1·0	20	25·10†	0·0427	+0·0005
25	0·3	1·0	25	25·20†	0·0429	+0·0007
25*	0·3	1·0	12	25·70†	0·0421	−0·0001
25*	0·3	1·0	12	24·65†	0·0420	−0·0002
25	0·3	1·0	20	25·20‡	0·0430	+0·0008
25	0·3	1·0	25	25·15‡	0·0429	+0·0007
25	0·3	2·0	25	25·20‡	0·0430	+0·0008
25	0·3	2·0	20	25·15‡	0·0429	+0·0007

These results proved to be too high and led to the conclusion that the ammonium sulphate was acted upon by the iodic mixture, liberating an additional portion of iodine. Experiments with ammonium sulphate verified the supposition, and the process is, therefore, less accurate in the presence of ammonium salts. In fact, ammonium sulphate in the amounts taken may be completely hydrolyzed in the course of three hours, about one-half of the iodine liberated by the sulphuric acid formed in the hydrolysis being available for estimation under the conditions of the foregoing determinations. When, however, the distillate is collected in a solution of potassium iodide containing sufficient acid to combine with the ammonia volatilized, iodine is liberated in amount equivalent to the entire quantity of sulphates present, and may be titrated with sodium thiosulphate.

The reaction between iodine and ammonia in alkaline solution, and the hydrolysis of ammonium salts, are undergoing further investigation by the writer.

The attempts to obtain a complete reaction by heating the mixture in a pressure bottle showed that the results of this procedure are low, although but slightly deficient, and cannot be used for estimating correctly the amount of aluminium salt in the solution.

The following method can be recommended as one giving constant results which correspond closely with the gravimetric

* Liquid in Voit flask not clear.
† New standard. ‡ New standard.

determinations and the theoretical amount of alumina in neutral aluminium chloride, sulphate, or alum, little time being necessary for a single determination:

Measure 25^{cm^3} of the approximately $\frac{n}{10}$ solution of the neutral aluminium salt to be analyzed into a Voit flask and to this add a mixture of 10^{cm^3} of a solution of neutral potassium iodate (30 grms. to a liter) and 1·0 grm. potassium iodide. Pass a current of hydrogen through the liquid and heat for fifteen to twenty-five minutes, or until the solution is nearly colorless, collecting the iodine liberated in a Drexel flask, about half full of water, in which 3 grms. of potassium iodide is dissolved. Titrate with sodium thiosulphate the iodine in the Drexel flask and that which remains in the solution in the Voit flask, and calculate the amount of alumina, Al_2O_3, corresponding to the iodine, 6I, liberated.

The writer wishes to thank Professor F. A. Gooch for friendly assistance during this investigation.

Art. XXIII.—*The Secondary Origin of Certain Granites;* by Reginald A. Daly, Ottawa, Canada.

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(*c*) Lake Superior islands and Logan sills.
(*d*) Cook County, Lake County and other localities.
C. The Sudbury intrusive sheet.
Synthetic discussion.
Magmatic assimilation.
Summary.
Asymmetry of the intrusive bodies.
Magmatic Differentiation.
General Application.

General thesis of the paper.—Igneous rocks originate in magmas. The discovery of the laws governing the immediate derivation of such rocks from their parent magmas is, therefore, not the final aim of the geologist. He is logically compelled to refer rocks themselves to the yet more fundamental problem of the origin of igneous magmas. Whence come the raw materials of basalt, gabbro, porphyry or granite?

One of the earliest answers to this question has been gradually assuming a systematic statement in the form of the "assimilation theory". This theory holds that some igneous rocks are derived from the compound magmas formed by the local fusion of solid rock in molten rock of a different chemical composition. The process can be imitated in the laboratory furnace, and has certainly operated on many igneous contacts in nature. Yet one of the very latest utterances of one of the world's greatest petrologists reads thus: "The untenability of the 'assimilation' or fusion theory I regard as definitely proved."* On the other hand, a no less well known authority claims assimilation on a large scale as a necessary stage in the preparation of the Christiania granite.† Brögger and many of his followers hold that the contact phenomena of this granite show that the assimilation theory breaks down even when applied to a most favorable case.

* "Die Unhaltbarkeit der 'Assimilations'- oder Einschmelzungs-Theorie betrachte ich als endgültig bewiesen."—J. H. L. Vogt, Die Silikatschmelzlösungen, Part II., Christiania, 1904, p. 225.

† F. Loewinson-Lessing, Comptes Rendus, 7th Session, International Geological Congress, 1899, p. 369.

This divergence of view is, of course, due to the lack of definite knowledge of the vital conditions controlling the activities of such an intrusive body as the Christiania granite. The study of its accessible contacts can, of itself alone, furnish neither proof nor disproof of the doctrine of wholesale assimilation. Without the aid of other geological data the attempt to solve the problem is like the attempt to produce graphically a complex curve of which but two points are known and fixed. Deep-seated assimilation about any magma chamber can only be finally discussed and evaluated if the complete form of the chamber and the complete composition of its rock-filling are at least tolerably known.

The present paper furnishes a brief discussion of a number of cases where it is believed that magmatic assimilation on a comparatively large scale has taken place. It is believed, further, that the geological conditions in these cases supply elements generally untouched in earlier discussions of the doctrine. The original magma had the composition of a gabbro intruded in the manner of sills; the invaded formations are ancient sandstones, both normal and feldspathic, with associated argillites or schists; the invaded formation, in every case, is more acid than the gabbro; the product of assimilation is always a granite graduating into granophyre. The acid magma is believed, however, to have been derived indirectly from the compound magma of assimilation through a systematic kind of differentiation. The primary cause of the differentiation is referred to the perfect or nearly perfect density stratification of each magmatic chamber.

The result of the investigation has been to confirm the writer's general theoretical conclusions on the subject of assimilation where it was necessarily introduced among the tests of the hypothesis of magmatic stoping*. Assimilation and differentiation are not antagonistic processes; both of them are involved in the secondary origin of some granites.

A. *The Sills of the British Columbia (International) Boundary.*

During the field season of 1904 the writer developed a geological structure section along the 49th parallel of latitude between Port Hill, Idaho, and Gateway, Montana, the two points where the Kootenay River crosses the boundary line between Canada and the United States. It was found that the mountains traversed by the section are for the most part composed of two very thick siliceous sedimentary formations which, in all probability, are of pre-Cambrian age. The two are conformable.

The lower formation has been called the Creston quartzite. It is a remarkably homogeneous, highly indurated light- to medium-gray sandstone, generally thick-platy in structure but

* This Journal, xv, 269, 1903, and xvi, 107, 1903.

occasionally interrupted by thin intercalations of argillaceous material. The formation is generally composed of nearly pure quartz with a little mica, but some bands are feldspathic to a notable extent. The total thickness of the formation is at least 9900 feet in the vicinity of Port Hill; its base was not directly observed.

Immediately overlying the Creston quartzite is the conformable Kitchener quartzite, composed of about 7400 feet of a highly ferruginous indurated sandstone. This formation is, in the field, distinguished from the Creston quartzite not only by the rusty color of the outcrops but also by a relatively thinner bedding and a greater proportion of micaceous cement, once somewhat argillaceous. Individual beds of the Kitchener quartzite are charged with detrital feldspar, but the formation as a whole is essentially composed of cemented quartz grains.

Dark-colored red, brown, and gray shales with thin intercalations of gray quartzite conformably overlie the Kitchener quartzite. The series, totalling 3200 feet in thickness, has been grouped under the name of the Moyie argillite. This formation appears but twice in the section and then only in comparatively small areas.

This great group of formations, from end to end of the section, has been mountain-built. A few open folds broken by faults appear in the eastern half of the belt, but the deformation has generally been due to the tilting of monoclinal blocks separated by strong normal faults and, more rarely, by thrusts. The tilting ranges though all angles up to verticality, but the average dip is less than forty-five degrees. In consequence of the deformation and subsequent denudation the edges of some 20,000 feet of well-bedded ancient sediment are now exposed for study. There have also come to light a number of thick sills of gabbro intruded at various horizons into the Kitchener quartzite and the upper part of the Creston quartzite. The intrusion and crystallization of the gabbro is believed to have taken place before the upturning of the sedimentaries. The faulting and tilting has repeated the outcrops of certain of the sills. One of the thickest of them has, along with the quartzites, been warped into one of the rare synclinal folds. The thickness of the sills varies from 100 feet to more than 2500 feet.

The main mass of each sill was uniformly found to consist of a hornblende gabbro with essential green (primary) hornblende and plagioclase (labradorite to anorthite, the latter in the cores of occasionally zoned feldspars). Accessory quartz, often in considerable amount, always accompanies the other accessories, which are titanite, titaniferous magnetite, and apatite with often a little biotite and sometimes a little orthoclase in addition. Epidote and chlorite are the principal secondary

minerals. The structure of the rock is typically hypidiomorphic-granular.

Already in those sills that range from 400 to 500 feet in thickness, the gabbro is acidified near its upper contact. The change from the normal composition is seen in the great increase of biotite, orthoclase, microperthite and interstitial quartz.

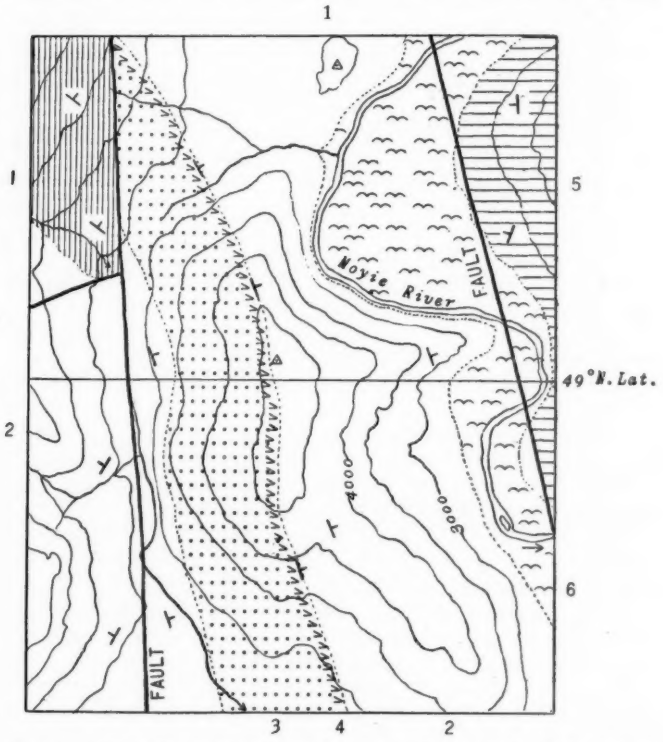

FIG. 1. Map of Moyie Sill, taken from plane-table sheet of the International Boundary Commission. 1. Moyie argillite. 2. Kitchener quartzite. 3. Hornblende gabbro sill. 4. Acidified (granite) zone of sill. 5. Creston quartzite. 6. Alluvium. Conventional sign for strike and dip. Scale: one inch = about one mile.

Biotite and quartz then assume the proportions of essential minerals. The quartz is characteristically in poikilitic relation to all the other constituents except orthoclase and microperthite, with which it is in true micrographic intergrowth. From this micropegmatite-bearing phase of the intrusive there is a gradual transition to the normal gabbro which thus composes the lower three-fourths or four-fifths of the sill.

The Moyie Sill.—The acidification of the upper zone of the gabbro being generally in a direct ratio to the strength of the sill, the phenomenon is specially marked in the greatest of all the intrusions. On account of its importance both in size and character, this rock-body is called the "Moyie Sill," the name referring to its situation on the Moyie River. A map and section of this sill are given in figs. 1 and 2, which illustrate one of the fault-blocks so characteristic of this part of the Boundary belt.* The sill is rather more than 2500 feet in thickness. It follows the bedding of the Kitchener quartzite, which here dips about sixty degrees to the eastward. The intrusive mass is seen to be cut off at its northern end by a master-fault which has dropped the Moyie argillite down into contact with the

2

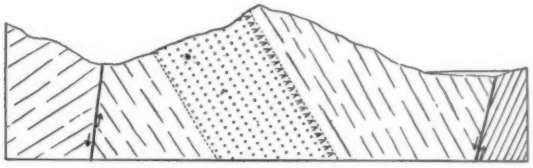

FIG. 2. Section of Moyie Sill, along line of the International Boundary.

gabbro. This faulting is believed to have occurred after the sill-intrusion. There is a complete lack of contact metamorphism in the argillite where it adjoins the gabbro.

Since the Moyie sill, throughout the six miles of linear outcrop studied, is in intrusive contact with the Kitchener quartzite alone, the other sedimentary formations need not here be described in detail. The Kitchener quartzite is, on the whole, a homogeneous terrane. On a fresh fracture the rock is seen to be a fine-grained, vitreous, light to darkish gray, well-bedded but tough, metamorphic sandstone, splitting with some readiness along the darker colored layers. The rusty color of the joint-surfaces and bedding planes is due to the leaching out and subsequent deposition of the iron contained in the pyrite, magnetite, etc., disseminated through the rock.

Under the microscope the rock is always seen to be essentially a fine-grained aggregate of interlocking quartz grains, seldom showing any direct traces of their detrital origin. The quartz mosaic is, in every thin section, shot through with abundant crystals of biotite which is often developed in phenocryst-like individuals occasionally as much as one centimeter in diameter. Sericitic muscovite is seldom absent as an essential, and sometimes rivals the biotite in abundance. Only

* All the line-drawings used in illustration of this paper have been made for the most part by the aid of a typewriter, provided with a few special keys. The machine permits of a great saving of time in the preparation of the manuscript drawings. Cf. this Journal, vol. xix, 1905, p. 227.

rarely is feldspar essential; in one slide it seems to compose ten to fifteen per cent of the rock. So far as observed, the feldspar of the staple quartzite is orthoclase. No sodiferous mineral has been certainly determined in the rock. Epidote, zoisite, titanite, magnetite, leucoxene, pyrite and zircon, besides chlorite, secondary after biotite, are the other, always subordinate, constituents.

In marked contrast to the normal quartzite is the rock collected at a point thirty feet from the upper contact of the Moyie sill. It is a very hard, vitreous, massive, light bluish gray quartzite carrying much feldspar. The whole rock seems to have been recrystallized. The granular-mosaic structure has been largely replaced by poikilitic and micrographic structures. Quartz is thus either regularly intergrown with feldspar or else encloses non-oriented individuals of the same mineral. The feldspar proved to be orthoclase, albite and microperthite, named in the order of their relative abundance. Biotite and sericitic muscovite are, as usual, in considerable amount. A little magnetite and a few minute crystals of anatase are the subordinate minerals. The characters of this contact phase point to the thorough metamorphism and notable feldspathization of the quartzite in the external contact zone of the gabbro.

The main mass of the sill-rock has the composition noted above as found in the sills generally. The grain is here medium to coarse, the structure hypidiomorphic-granular.

At the lower contact the grain of the gabbro is somewhat finer than in the interior of the sill, but the rock is still medium-grained and never compact. At the same time, interstitial and poikilitic quartz, along with biotite, orthoclase and microperthitic feldspar, are increased in amount. There is thus some acidification of the sill at its lower contact, though the rock is still gabbroid in macroscopic appearance and has hornblende and plagioclase (andesine to labradorite) as the chief constituents. Acidification of this order is visible for at least 200 feet from the lower contact. The intrusive rock is yet more abundantly charged with quartz, biotite and alkaline feldspars in the vicinity of the occasional xenoliths torn from the invaded quartzites.

The conditions are different at the upper contact. They may be readily studied on the wagon-road that threads the floor of the western meridional valley, shown in fig. 1. From the upper contact inward for a perpendicular distance of about 150 feet the intrusive is a highly siliceous rock, the mineralogical composition of which is shown in Table I and Table II. The structure of this rock varies irregularly, even in the same slide, from the hypidiomorphic granular of granite to the structure of granophyre or micropegmatite.

TABLE I.

Mineralogical composition of Rocks showing secondary derivation of Granite. (Essential minerals noted in italics.)

I. MOYIE SILL.

Gabbro.	Intermediate rock.	Granophyre-granite.
Hornblende	*Hornblende*	*Biotite*
Labradorite	*Biotite*	*Soda orthoclase*
Quartz	*Andesine*	*Microperthite*
Titanite	Quartz	*Micropegmatite*
Biotite	Chlorite	*Quartz*
Apatite	Titanite	Andesine
	Titanif. magnetite	Muscovite
	Apatite	Titanif. magnetite
		Apatite
		Calcite, epidote, kaolin

Country rocks: highly acid mica-bearing quartzite, sometimes slightly feldspathic, containing quartz, biotite and muscovite (sericite) as principal constituents, with orthoclase, epidote, titanite, magnetite, pyrite, zoisite, chlorite, leucoxene and zircon as subordinate minerals. Occasionally a thin layer or parting of more argillaceous composition.

II. PIGEON POINT.

Gabbro.	Intermediate rock.	Granophyre-granite.
Olivine	*Hornblende*	*Anorthoclase*
Diallagic augite	*Anorthoclase*	*Oligoclase*
Basic labradorite	*Plagioclase*	*Quartz*
Apatite	*Quartz*	*Micropegmatite*
Titanif. magnetite	Micropegmatite	*Chlorite*
	Chlorite	Augite (occasional)
	Magnetite	Muscovite
	Apatite	Rutile
	Rutile	Leucoxene
		Hematite
		Apatite

Country rocks: feldspathic quartzite and slate, containing quartz, orthoclase, plagioclase, chlorite, green mica, biotite, magnetite, leucoxene. Feldspar sometimes 75 per cent of the quartzite.

III. SUDBURY DISTRICT.

Norite.	Intermediate rock.	Granophyre-granite.
Hypersthene	*Hornblende* or	*Biotite*
Augite	*Hypersthene*	*Orthoclase*
Bytownite	*Biotite*	*Micropegmatite*
Quartz	*Oligoclase-andesine*	*Microperthite*
Biotite	*Orthoclase*	*Microcline*
Hornblende	*Microperthite*	*Oligoclase*
Apatite	Quartz	*Quartz*
Magnetite	Epidote	Epidote
Sulphides	Apatite	Ilmenite
	Magnetite	Titanite

Country-rocks: sandstones, graywackes, slates, conglomerates, greenstones, volcanic tuffs and granitoid gneiss.

TABLE II.

Showing the weight percentages of minerals as determined by the Rosiwal method.*

	1.	2.	3.	4.	5.	6.	7.
Hornblende	58·7	54·8	42·9	49·4	---	---	---
Biotite	·9	---	6·6	22·0	8·9	22·0	15·2
Labradorite, Ab_1An_1–Ab_1An_2	34·8	25·6	---	---	---	---	---
Andesine, Ab_1An_2	---	---	18·5	16·5	---	---	---
Oligoclase, Ab_2An_1	---	---	---	---	1·5	1·5	1·0
Soda-bearing orthoclase	---	---	5·5	---	24·9	29·1	32·5
Microperthite	---	---	---	---	---	---	3·9
Quartz	4·0	6·3	22·8	11·7	57·1	46·0	41·6
Muscovite	---	---	---	---	3·2	---	4·6
Apatite	·2	---	---	·3	---	·5	·2
Titanite	1·4	2·0	3·7	---	---	---	---
Magnetite	---	·3	---	---	1·9	·5	1·0
Chlorite	---	11·0	---	---	---	---	---
Calcite	---	---	---	---	2·5	·4	---

Total is 100 in each case.

1. Normal unacidified gabbro from sill about eleven miles east of the Moyie sill.

Nos. 2 to 7 inclusive are types from the Moyie sill, specimens taken thus :

2. Thirty feet from lower contact.
3. Two hundred feet from lower contact.
4. Two hundred feet from upper contact.
5. Fifty feet from upper contact.
6. Forty feet from upper contact.
7. Fifteen feet from upper contact.

Table II was constructed by the use of the Rosiwal method for the determination of the relative quantities of the different constituents. The values are only approximate, owing to the difficulties of exact measurement and identification of the mineral grains. No account was taken of the sometimes abundant grains of epidote, occasional grains of calcite (measured in one instance), and often rather abundant scales of kaolin which occur in the slides. These minerals are products of the alteration of the feldspars, that alteration affording another difficulty in using the Rosiwal method for this suite of rocks. The proportions of the micas are probably too high on account of their not being even approximately equidimensional. Though these rocks do not lend themselves to a very satisfactory employment of the method, and though the table cannot be considered as accurate, the strong contrasts between the acid and basic phases of the sill are clearly evident.

* Verh. Wien. Geol. Reichs-Anst., vol. xxxii, 1898, pp. 143 ff.

Since the compositions of the hornblende, biotite and soda-bearing orthoclase are not known, the chemical analyses cannot be calculated from Table II. Direct chemical analyses of types Nos. 1 and 7 in Table II have been made by Professor Dittrich, of Heidelberg, and are recorded in Table III.

TABLE III.

	1.	2.
SiO_2	51·92%	71·69%
TiO_2	·83	·59
Al_2O_3	14·13	13·29
Fe_2O_3	2·97	·83
FeO	6·92	4·23
MnO	·14	·09
MgO	8·22	1·28
CaO	11·53	1·66
Na_2O	1·38	2·48
K_2O	·47	2·37
H_2O (below 110° C.)	·10	·14
H_2O (above 110° C.)	1·07	1·31
P_2O_5	·04	·07
CO_2	·06	·13
	99·78	100·16
Sp. gr.	3·000	2·773

1. Normal unacidified gabbro from sill about eleven miles east of the Moyie sill.
2. Acid rock fifteen feet from upper contact of the Moyie sill.

The rock of col. 2 belongs to the granite family. The silica is normal (higher in types of cols. 5 and 6, Table II), but the total of the alkalies is extraordinarily low, namely 4·85 per cent, or ·76 per cent lower than the total of the potash and soda in the least alkaline among the twenty-six types of granite analyses selected for Rosenbusch's "Elemente der Gesteinslehre." The comparatively high content of lime is probably to be referred to a not unimportant mixture of lime feldspar and alkaline feldspar in isomorphous relation, as well as to a small amount of secondary epidote.

Col. 1 shows the gabbro to be a normal type in some respects, but the high content of silica and relatively low content of alumina and soda are abnormal for gabbro. These features are partly due to the predominance of hornblende over feldspar and to the presence of free quartz. It can be seen by inspection of cols. 1 and 2, Table II, that the gabbro at the bottom of the Moyie sill would give an analysis very close to that of col. 1, Table III, which represents a good type of the

average gabbro from the many sills of the Boundary belt. A comparison of cols. 2, 4 and 7, Table II, shows that col. 4 corresponds to a rock-type intermediate between the two types actually analyzed. It is planned that a rather complete set of total analyses of the various phases of the Moyie sill will be published in the final report of the Chief Commissioner for Canada on Boundary Surveys.

Partially absorbed inclusions of the quartzite occur also in the upper, granitic zone of the intrusive.

Next to the peculiar granite-granophyre is a hundred-foot (thick) zone of intermediate rock which, with rapid transition,

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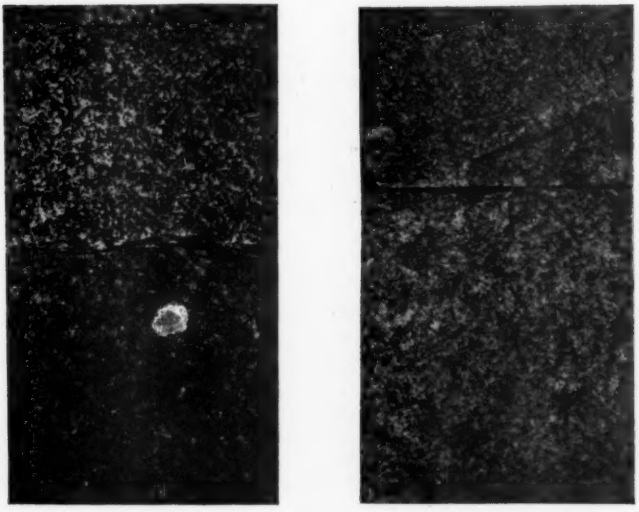

FIG. 3. Photograph of specimens showing contrast of color between a basic and a normal phase of the gabbro of the British Columbia sills and between both of these and two phases of the Moyie Sill granophyre-granite shown on the left.

replaces the acid rock as the section is thus carried inwards through the sill. The mineralogical composition of this intermediate rock is shown in Tables I and II.

The structure is again hypidiomorphic-granular with continual gradations into the granophyric. The grain varies from medium to rather coarse.

The intermediate rock grades imperceptibly into the normal gabbro of the internal part of the great intrusive body.

The variation in mineral composition among the zones of granite, intermediate rock and gabbro are shown in Table II.

The profound macroscopic differences of aspect are imperfectly illustrated in fig. 3, which shows the variation of color-tint. The corresponding variations in the specific gravity of specimens taken in the cross-section of the sill is shown in the following table:

Locality of specimen.	Sp. gr.
15 feet from upper contact	2·773
40 " " " "	2·784
50 " " " "	2·800
Average for granite zone about	2·790
200 feet from upper contact	3·020
Average for middle of sill about	3·025
200 feet from lower contact	2·967
30 feet " " "	2·980

A series of determinations showed in addition that the average specific gravity of the normal gabbro in all the sills of the Boundary belt is about 3·020.

Exomorphic contact action was observed at both upper and lower contacts with the Kitchener quartzite. It has taken the form of increasing the already high induration of the sediments with an accompanying special development of biotite at both upper and lower contacts. Though there is evidence of the feldspathization of the quartzite at the upper contact, none has yet been forthcoming for the lower contact, where, nevertheless, feldspar may have been similarly introduced from the magma. Doubtless on account of the chemical nature of the invaded sediments contact metamorphism is not conspicuous in the field, nor is it easy to trace its influence. The writer's impression is that the effects are more manifest, the action having been more intense, at the upper contact than at the lower, but additional field study will be required to test the real truth of that impression.

Apart from the development of exotic feldspar in the quartzite, indications of true pneumatolytic action seem to be lacking at both contacts. Mineral veins, including quartz veins, except occasional stringers of quartz, are conspicuously absent.

Field Hypothesis.—The hypothesis adopted in the field to explain these rocks and their relations involved a secondary origin for the granite-granophyre zone at the top of the sill. That zone was thereby interpreted as due to the contact-action of the gabbro intrusion on the adjacent Kitchener quartzite; digestion and assimilation of the sediments both on the main or "molar" contacts and on the peripheries of blocks shattered off from those contacts, was credited with the formation of a new compound magma from which the highly acid and somewhat anomalous granite was derived. The fact that the acid

rock is practically confined to the upper contact-zone was explained by the collection of the products of digestion at the upper contact by gravitative adjustment in the magma. The low density of the locally formed new magma of assimilation would tend to effect its upward diffusion and the consequent cleansing of the heavier gabbro magma from such acid material. The comparatively slight acidification at the lower contact was attributed to the solution of the quartzite in the period immediately preceding the final consolidation of the sill; at that time the viscosity of the magma was too great to allow of the upward diffusion.

A principal test for such a hypothesis is obvious. If it be true, there should be other examples among the great basic sills cutting siliceous sediments. It has already been noted that there is actually such acidification of the other gabbro sills encountered between Port Hill and Gateway, and that in them the acidification is always most marked at the upper contact. Much more striking examples have been described with unusual thoroughness in Minnesota and Ontario. The comparison of these other cases is so important that the best established types will here be sketched and illustrated in some detail. The further discussiou of the Moyie sill will be postponed to later pages, in which a synthetic treatment of all the examples will be undertaken.

B. *Occurrences in Minnesota.*

(*a*) The very able and specially detailed memoir of Bayley on the rocks of Pigeon Point contains, doubtless, the most elaborate argument in favor of the secondary origin of some granites. A brief summary of his facts and conclusions may well be given in the works of Bayley's own outline forming the introduction to his paper.

"Pigeon Point is the northeastern extremity of Minnesota. It is one of a series of parallel points extending from Minnesota and Canada eastward into Lake Superior. Its backbone is a great east and west dike-like mass of a gray, coarse-grained rock that has always been called gabbro. This consists of phenocrysts of plagioclase in a diabasic groundmass of the same mineral, olivine and diallage, and consequently, it is a diabase porphyrite. . . . .

"The rocks through which the gabbro cuts are evenly bedded slates and indurated sandstones of Animikie age. They dip south-southeast at 15 to 20 degrees, except at a very few places near the contact with other rocks, where they are more or less contorted. . . . .

"The most interesting features in the geology of the point relate to the series of rocks usually occurring between the gabbro and the clastic beds. Beginning on the gabbro side the series

comprises in succession coarse-grained red rocks, a fine-grained red rock that is sometimes porphyritic and a well-marked belt of altered quartzites.

"The fine-grained red rock has all the characteristics of an eruptive. It sends dikes into the contiguous bedded rocks, and consists essentially of a hypidiomorphic granular aggregate of plagioclase, anorthoclase and quartz. The quartz and anorthoclase often form micropegmatite, while the plagioclase is in comparatively large grains, some of which have hardly defined idiomorphic outlines. At a few places this red rock is porphyritic, with bipyramidal quartz crystals imbedded in a red granophyric groundmass. The rock is similar to many of the augite-syenites described by Irving as occurring in the Keweenawan series, and is in structure and composition a quartz keratophyre.

"The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between these two. The variety nearest the gabbro differs but slightly from the basic eruptive. In addition to the gabbro components it contains a little quartz and red feldspar—constituents derived from the keratophyre. As the latter rock is approached, the augite, olivine, and plagioclase disappear, while increased quantities of quartz, red feldspar, and brown hornblende make their appearance, and the rock becomes more and more like the fine-grained red rock. Finally the hornblende disappears and the keratophyre is reached. Since the intermediate rocks occur only between the gabbro and the fine-grained red rock, and since all gradations in composition between the two end members of the series are represented, the coarse-grained red rocks are regarded as contact products formed by the intermingling of the gabbro and the keratophyre magmas."*

After describing the compound external zone of contact metamorphism, Bayley continues:

"From the above-mentioned facts it is concluded that the contact belt represents Animikie slates and quartzites that have been altered near their contact with an intrusive rock. The metamorphism of the quartzites has resulted simply in the recrystallization of the quartz and feldspar of the fragmental grains, with the addition, perhaps, of a little orthoclase.

"Since, in several instances, the gabbro is in direct contact with the metamorphosed rocks, while the keratophyre is not to be found in the neighborhood, it is inferred that the former rock and not the latter was the cause of the contact action."

The significant paragraph follows:

"Inclusions of fragmentals in the gabbro and the keratophyre have alike suffered the same alterations as have taken place in the various members of the contact belt, with this difference, that quartzite inclusions in the basic rock are often surrounded by a

* W. S. Bayley, Bull. 109, U. S. Geol. Survey, 1893, p. 11.

rim of red rock, identical in all its properties with the keratophyre. This suggests that the keratophyre itself may be of contact origin."

Finally:

"The conclusion reached is that, in all probability, the keratophyre is of contact origin—that is, it was produced by the

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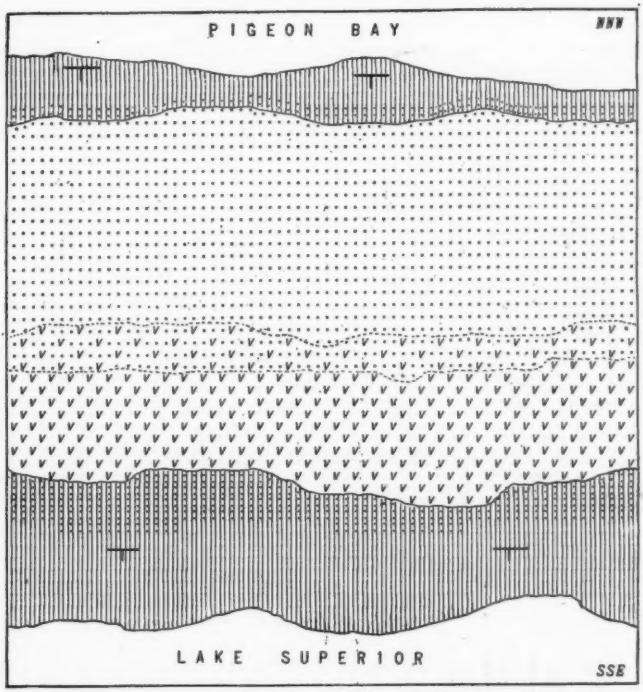


FIG. 4. Diagrammatic map of part of Pigeon Point, Minnesota, showing general relations among the different rock formations; after Bayley.

1. Animikie quartzites and slates. 2. Contact zone in the Animikie sedimentaries. 3. Olivine gabbro. 4. Intermediate rock. 5. Soda granite and keratophyre. Conventional sign for strike and dip. Scale: nine inches = one mile.

fusion of the slates and quartzites of the Animikie through the action upon them of the 'gabbro.' The magma thus formed then acted in all respects like an intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda-granite under certain circumstances, and under others as a quartz-keratophyre."*

*Op. cit., p. 12.

The diagrammatic map of fig. 4 generalizes the field relations as expressed in Bayley's maps. There have been omitted from the diagram certain complexities in the maps showing the actual geology. The essential features are thus made all the more evident; at the same time it is believed that this arbitrary treatment of the maps does not introduce error in principles.

A summary of the mineralogical compositions of the gabbro, intermediate rock, granite-keratophyre (granophyre) and invaded sediments is given in Table I. The correlative differences in chemical constitution are noted in Table IV.

TABLE IV.

Selected Analyses, Bayley on Pigeon Pt.

	A.	B.	C.	D.	E.	F.
SiO_2	49·88%	57·98	72·42	73·85	59·71	70·31
TiO_2	1·19	1·75	·40	·05	tr.	tr.
Al_2O_3	18·55	13·58	13·04	10·91	18·32	12·81
Fe_2O_3	2·06	3·11	·68	6·98	8·11	7·26
FeO	8·37	8·68	2·49	·89	·85	·88
MnO	·09	·13	·09	....	....	....
CaO	9·72	2·01	·66	·44	1·05	·60
BaO	·02	·04	·15	....	....	....
MgO	5·77	2·87	·58	1·52	3·54	2·03
K_2O	·68	3·44	4·97	1·39	3·43	1·90
Na_2O	2·59	3 56	3·44	2·28	1·93	2·19
H_2O	1·04	2·47	1·21	1·88	3·24	2·22
P_2O_5	·16	·29	·20	....	....	....
	100·12	99 91	100·33	100·19	100·18	100·20
Sp. gr.	2·923–2·970	circa 2·740	2·620	not given, prob. ca 2·70	not given, prob. ca 2·75	

A. Olivine diabase; aver. of five specimens..p. 37
B. Intermediate rock 63
C. Red granite; aver. of 7 specimens..... 56
D. Unaltered quartzites; aver. comp. 90
E. Unaltered slate..... 90
F. Approximation to aver. comp. of sediments 113

The general similarity in the character and spatial arrangement of the rocks at Pigeon Point and on the Moyie River is apparent. The comparison of conditions is obscure only as relates to the structural cross-section. The Moyie intrusive is unquestionably a sill. The underground relations of the Pigeon Point intrusive, for lack of decisive field evidence, have not been fixed beyond the possibility of doubt. Bayley says:

"The most prominent features of these gabbro masses are those of dikes. As has already been mentioned, the larger one [the one referred to in the present paper] in many places presents perpendicular walls both to the north and to the south. It occupies all the highest portions of the point, and these are in a straight line. It has the appearance of an intrusive mass, and is like any one of those forming the numerous points to the north of the international boundary line. It has been regarded as a dike by both Irving and N. H. Winchell. Its contact with the sedimentary rocks is only occasionally to be seen. At several of these contacts the eruptive has the appearance of having escaped from between the dike walls and thrust itself for a short distance between the fragmental beds, or having piled itself up around the dike orifice and overlapped the intruded rocks. . . . . At only two places on the north shore do the fragmental rocks appear, and at these places they are far below where they should be were they interbedded with the gabbro, and in neither case is the contact like that of interbedded eruptive and sedimentary rocks."

He concludes that:

"The larger mass of the Pigeon Point gabbro is in the form of a dike, which has broken through its walls at certain places and intruded itself between the strata of the surrounding rocks."*

In accordance with his view Bayley's cross-sections show vertical contacts among all the igneous rock members and also between sediments and eruptives.

On the other hand, Professor N. H. Winchell states, in a personal letter to the writer:

"All my observations bearing on the relations of the gabbro to the Animikie on Pigeon Point lead to the conclusion that the gabbro is later than the Animikie. But the term gabbro here is made to include those coarse non-ophitic dikes that resemble gabbro and which are also allied to diabase. There are abundant places where this rock is in the form of sills in the Animikie. The great backbone of Pigeon Point, which is the most distinctly gabbroid of the intrusive rocks, is simply a large example of a sill, while, as I interpret the structure, many of the dikes cutting the Animikie are only contemporary offshoots from it."

With Winchell's view there agrees the observation of Bayley that the feldspar phenocrysts of the porphyritic gabbro are sometimes "arranged in rude layers parallel to the dip surfaces of the quartzite. Their longer axes are usually in the direction of the dip of the sedimentary rocks."† This orientation suggests flow-structure parallel to contacts. Professor Bayley has, by letter, restated to the writer his conclusion that "the gabbro was intruded as a boss or huge dike, certainly not

* Op. cit., pp. 22-23. † Op. cit., p. 23.

as a sill," but adds the remark that "while the contacts of the quartzites with the red rock and gabbro so far as they were seen are vertical, it does not necessarily follow that they are vertical with depth." He continues: "I have no means of knowing the date of the intrusion. With respect to the tilting (of the quartzites) my guess is that the intrusion was prior to the latest tilting, but later than an earlier tilting lakeward."

The possibility that the Pigeon Point eruptive is either a true sill only locally breaking across the bedding of the sediments or at any rate dips as a whole to the south-southeastward, is further suggested by the analogy of the many undoubted sills of gabbro cutting the southerly to southeasterly dipping Animikie of Minnesota. Some of these sills have likewise zones of soda granite lying between the gabbro and the sediments on the southerly flank of the gabbro. Thus in those cases the sediments dip under the gabbro on the one side of the eruptive body and away from the granite on the other side.

Bayley's full and trenchant argument for the contact origin of the soda granite and granophyre need not be repeated. The independent origin of the acid rock is rendered highly improbable by the occurrences of the intermediate rock lying directly between the gabbro and the sediments without the intervention of the true granite or granophyre.

The efficiency of contact-shattering in aiding the digestion of the slates and quartzites is strikingly manifest in Bayley's descriptions.

"Very close to the red rock appears a belt in which the various rocks are in the most complicated relations imaginable. In the eastern portion of the point this belt is well seen on the southern shore, about one-third of a mile from the end of the point. (See Pl. XVI.) Here the red rock is exposed in low cliffs, and in it are small, sharp slate and quartzite inclusions, into which the red rock penetrates in every direction. The exact line of contact between the red rock and the bedded fragmentals cannot be detected, as they appear to merge gradually into one another, the latter becoming redder and redder as they approach the former, which penetrates them in veins and dikes, and finally includes numerous pieces in such a way as to yield a good eruptive breccia."

"Some of the inclusions are very sharp and but little altered, while others are partially dissolved, and are surrounded by concentric zones, resulting from the action of the red rock upon the material of the inclusion, and the reciprocal effect of the partially dissolved inclusion upon that portion of the red-rock magma immediately contiguous to it. . . . . Thus it would seem to be a fact beyond controversy that the red rock is the immediate cause of the alteration noticed in the fragmental rocks and of the brec-

cia observed along its contact with them. If, however, the contact belt is examined very closely, it is found that although the red rock is always accompanied by a zone of this belt, there are localities in which the latter occurs without the presence of the former. . . . . The metamorphosing rock seems to be the gabbro. Just as in the case of the contacts with the red rock, the quartzites become mottled as they approach the eruptive, and inclusions of the former in the latter are so frequent that there appears to be a gradual transition between the two rocks."*

Similar shatter-breccias are described at the northern contact. The metamorphism of the inclusions is there the same in kind as on the southern contact but is less intense.†

(*b*) A significant discovery was made at a mining prospect on Governor's Island just south of Pigeon Point. The shaft started in hardened slate at the surface, then struck red quartzite and finally red granite where the sinking was discontinued. In this case there is no question that the sediments overlie the granite in a relation similar to that involved in the sill theory of the Pigeon Point intrusive.‡

(*c*) Parallels to the Pigeon Point case have also been found on Spar, Jarvis and Victoria Islands.§ Lawson has described other examples among the Logan sills of Lake Superior, and says that the sills are repeated by step-faults gently tilting the sills to the southeast at the maximum angle of five degrees.‖

(*d*) Grant describes the great gabbro area of Cook County, Minnesota, as a laccolith in the gently dipping Animikie quartzites, slates and graywackes. He maps soda granites passing into alkaline quartz porphyries on the southern flank of the gabbro or in it. This latter occurrence is possibly to be related to the occasional horizontal dips of the Animikie.¶

N. H. Winchell maps a broad band of the red granite to the southward of the huge gabbro mass of Lake County. He states that the southern limit of the gabbro forms the northern limit of the red granite, but that there are numerous places where these rocks are intricately interbedded and in some instances isolated areas of the red rock are surrounded by gabbro.** The official atlas of the Minnesota Geological Survey indicates still other large-scale examples of the same or similar close relations of gabbro and red granite—notably those mapped in vol. vi, plates 68, 69, 84, 85 and 87.

* Op. cit., pp. 28–29. † Op. cit., p. 81.

‡ Final Report, Geol. Surv. of Minnesota, vol. iv, 1899, p. 516, and vol. v, 900, p. 799.

§ Bayley, op. cit., p. 30; cf. E. D. Ingall, Ann. Rep. Geol. Surv. Canada, 1888, Pt. H, pp. 45 and 49.

‖ Bull. 8, Geol. Surv. Minnesota, 1893, pp. 30–33–42–44.

¶ Final Rep. Minn. Geol. Surv., vol. iv, 1899, pp. 323 and 326.

** Ibid., pp. 296–7.

C. *The Sudbury Intrusive Sheet.*

A still more remarkable parallel to the conditions of the Moyie sill has been rather fully described by Barlow and Coleman, following the earlier work of Walker in their respective memoirs on the geology of the Sudbury District, Ontario. In the scale of the various related phenomena, in the wonderfully systematic arrangement of the different rock-formations, and in the occurrence of valuable ore-bodies directly and geneti-

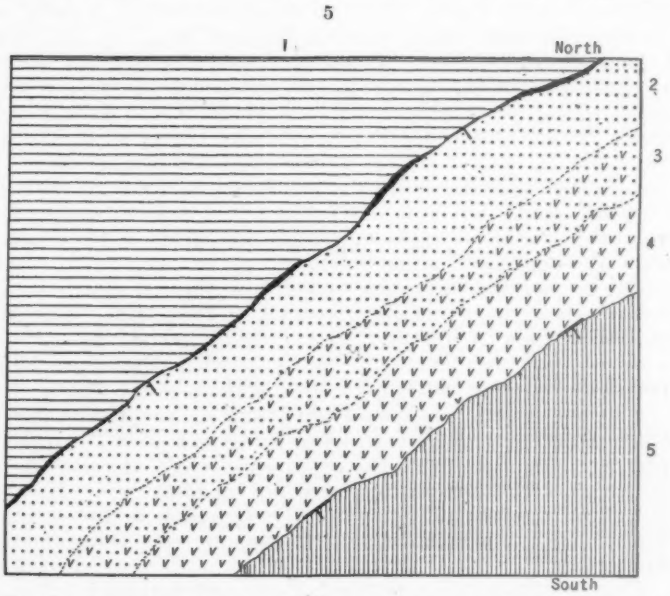


FIG. 5. Diagrammatic map of part of the Northern Nickel Range, Sudbury District, Ontario; after Coleman.

1. Granitoid gneiss, greenstones and graywackes. 2. Norite. 3. Intermediate rock, transitional between norite and micropegmatite. 4. Micropegmatite. 5. Slates, sandstones and volcanic tuffs. (The position of the sulphide ores shown by heavy black line.) Conventional sign for strike and dip. Scale: one inch = two miles.

cally associated with the intrusive, the Sudbury District example stands unique in petrographical records.

The latest reports of Barlow and Coleman agree in the conclusion that the famous nickel-bearing eruptive has the form of an enormous intrusive sill of a composition exactly analogous to that of the Moyie sill excepting as regards the development of the valuable sulphides. It is "a vast sheet of eruptive rock having a basin shape; a sheet nearly 40 miles long

and 17 miles wide, and probably a mile and half to two miles thick on the average, if the (average centripetal) dip (of the sheet) is 45 degrees."*

This great sheet cuts sediments and schists referred to the Laurentian and Upper Huronian. Their general field relations are summarized in the diagrammatic map of fig. 5, drawn from a part of Coleman's official map of the "Northern Nickel Range." Again the gabbroid rock (norite) is seen to be concentrated on the lower contact of the sheet, the acid rock, micropegmatite or granophyre, graduating into true granite, on its upper contact, while between the two is a zone of intermediate rock. On the "Southern Nickel Range" across the spoon-shaped basin, Barlow has determined the same arrangement of acid, intermediate and basic zones in the sheet, which there, however, agreeably with the basin theory of structure, has a northerly dip; so that in this case, the norite occurs on the south side of the sheet, the granite-granophyre zone on its northern side. On the basin theory of the structure, the volume of the granite-granophyre in this sheet is to be measured by hundreds of cubic miles.

All around the basin the nickel ores form a more or less continuous zone at the lower contact of the norite. The sulphides are also to be found in especial abundance as segregations in apophysal offshoots of the norite where the basic magma penetrated fissures outside the lower contact of the sheet.

Coleman states that where the band of eruptive (outcrop edge of the sheet) is narrow, there is less change in the rock in passing from the lower to the upper contact, the most basic norite as well as ore being absent for the most part. He also notes the absence of granophyre or granite in the smaller intrusions of the norite which occasionally appear outside the main basin.†

Eruptive breccias due to the shattering of the invaded formations by the hot magma are found at both upper and lower contacts.‡

Coleman notes that in the northern nickel range the contact metamorphism is more intense next the upper acid zone than next the norite. He explains this as possibly due to the fact that the rocks at the lower contact were already well crystallized before the intrusion took place, while the sediments along the upper contact were then capable of notable minera-

*A. P. Coleman, Rep. Bureau of Mines, Ontario, 1903, p. 277. Cf. A. E. Barlow, Ann. Rep. Geol. Surv. Canada, vol. xiv, 1904, p. 72; also stereogram accompanying Coleman's report.

†1904 report, p. 212, and 1903 report, p. 286.

‡A. E. Barlow, op. cit., pp. 122, 129 and plates; A. P. Coleman, Rep. Bureau of Mines, Ontario, 1904, p. 213; T. L. Walker, Quart. Jour. Geol. Soc., vol. liii, 1897, p. 54.

logical changes. The metamorphism on the upper contact extends outward for a distance of from 1000 to 1500 feet.

There seems to be a decided lack of pneumatolytic action (other than that due to water vapor) incident to the intrusion.*

Coleman has concluded that the intrusion of the sheets *antedated* the synclinal warping of the region to which the present basin shape of the sheet is attributed.†

The mineralogical compositions of the norite, intermediate rock and micropegmatite-granite are summarized in Table I. Their chemical compositions are entered in Table V, taken from Walker's paper, page 56. The corresponding specific gravities also show the significant homologies existing between these rocks and those of Pigeon Point and of the Moyie sill. The value of a close study of these tables will appear in the following general comparison of the rocks and of their relations to one another.

TABLE V.

	1.	2.	3.	4.	5.
SiO_2	49·90%	51·52%	64·85%	69·27%	67·76%
TiO_2	1·47	1·39	----	·78	·46
Al_2O_3	16·32	19·77	11·44	12·56	14·00
Fe_2O_3	----	·47	2·94	2·89	----
FeO	13·54	6·77	6·02	4·51	5·18
MgO	6·22	6·49	1·60	·91	1·00
CaO	6·58	8·16	3·49	1·44	4·28
Na_2O	1·82	2·66	3·92	3·12	5·22
K_2O	2·25	·70	3·02	3·05	1·19
H_2O	·76	1·68	·78	·76	1·01
P_2O_5	·17	·10	·24	·06	·19
	99·03	99·71	98·30	99·35	100·29
Sp. gr.	3·026	2·832	2·788	2·724	2·709

1 to 5—"Specimens range from north to south" across the Sudbury intrusive sheet, that is, from near lower contact (No. 1) to near upper contact (No. 5).

Synthetic Discussion.

Magmatic Assimilation.—The secondary origin of granite has long been maintained by N. H. Winchell, who has referred to the Pigeon Point case as, among others, demonstrating the fact.‡ Bayley came to the same belief for the granite and granophyre of the point, but did not extend his argument in detail to cover other occurrences among the Minnesota intrusives. On the other hand, the principle has not been accepted

* A. E. Barlow, op. cit., p. 129.
† 1903 report, p. 277.
‡ Final Rep. Minn. Geol. Surv., vol. v, 1900, p. 62, etc.

as applying to these localities even by Van Hise, whose rare knowledge of Lake Superior geology must give his opinion exceptional weight.* Even the latest text-books of geology give most inadequate treatment of the doctrine though it refers to one of the most important problems in the whole field of geology. Doubtless the majority of petrologists are to-day unfavorable to the assimilation theory of granite and its relatives except as it applies to a very limited, in point of volume insignificant, modification of certain magmas at their contacts.

Van Hise's chief argument against the contact origin of the Pigeon Point granite emphasizes the fact that that rock has not the chemical composition either of the sedimentary formation or (as especially shown in the surplus of alkalies and the deficiency of iron in the granophyre-granite) of a direct mixture of gabbro and sediments.† The much quoted argument of Brögger with reference to the Norwegian granites is based on a similar fact.‡ Many other writers have, on a similar ground, excluded contact assimilation as playing any considerable part in the formation of abyssal or hypabyssal magmas.

In practically every case the opponents of the assimilation theory have treated of the assimilation as essentially a static phenomenon. Each interpretation of field facts has been phrased in terms of magmatic differentiation *versus* magmatic assimilation as explaining the eruptive rocks actually seen on the contacts discussed. Nothing seems more probable, however, than that such rocks are often to be referred to the compound process of assimilation accompanied and followed by magmatic differentiation. The chemical composition of an intrusive rock at a contact of magmatic assimilation is thus not simply the direct product of digestion. It is the net result of rearrangements brought about in the compound magma of assimilation. In the magma, intrusion currents, convection currents and the currents set up by the sinking or rising of xenoliths must take a part in destroying any simple relation between the chemical constitutions of the intrusive and invaded formations. Still more effective may be the laws of differentiation in a magma made heterogeneous by the absorption of foreign material which is itself generally heterogeneous. The formation of eutectic compounds or mixtures, the development of density stratification, and other causes for the chemical and physical resorting of materials in the new magma ought certainly to be regarded as of powerful effect in the same sense.

A second fundamental principle has as a rule been disregarded in the discussions on magmatic assimilation. The *form*

* Monograph XLVII, U. S. Geol. Surv., 1904, pp. 730–733.
† Op. cit., p. 733.
‡ Die Eruptivgesteine des Kristianiagebietes, Pt. II, 1895, p. 130.

of the intrusive body, and the relation of the accessible points of its contacts to that form as a whole, must be taken into account. If, for example, differentiation of the compound magma has taken place so as to produce within the magma chamber layers of magma of different density, the lightest at the top, the heaviest at the bottom, the actual chemical composition of the resulting rock at any contact will depend directly on the magmatic stratum rather than on the composition of the adjacent country-rocks.

Thirdly, the method of intrusion is of primary significance in the discussion of assimilation in a given instance. There are strong reasons for believing that the subterranean chambers of stocks and batholiths have been opened largely or at least in part through magmatic "stoping," whereby magmas have made their way upward through the invaded formations by engulfing suite after suite of blocks shattered off from those formations by the heat of the intrusives.* In such a case the destructive action at the molar contact is chiefly physical, and chemical solution is subordinate. Most of the solution takes place in the complete digestion of the sunken blocks and is therefore abyssal rather than marginal. The conditions are peculiarly favorable for the systematic differentiation of the new compound magma. The chemical composition of the intrusive at any contact will thus depend on the constitution of a (possibly well differentiated) magma containing materials won from *all* the invaded formations and not simply materials won from the immediately adjacent country-rock. Brögger's argument derived from the low content of lime in the Christiania granite cutting thick limestones (themselves overlying an enormous thickness of crystalline schists, etc.) is clearly inconclusive until it can be shown that this and the other two factors just noted have not been at work.†

Magmatic stoping has, in all probability, taken place to some extent in the great intrusive body at Pigeon Point. The specific gravity of the gabbro varies from 2·923 to 2·970. Molten at 1400 degrees Cent., its specific gravity, at atmospheric pressure, would be not far from 2·43 to 2·48. The specific gravities of the intermediate rock and granite are respectively 2·740 and 2·620; molten at 1400 degrees Cent., they would, at atmospheric pressure, be about 2·30 and 2·19 respectively. The specific gravity of the invaded sediment varies from 2·70 to about 2·75. Blocks of the quartzite and slate immersed in any of the molten magmas and there assuming the temperature of 1400 degrees Cent., would at the same

* Cf. R. A. Daly, The Mechanics of Igneous Intrusion, this Journal, vol. xv, 1903, p. 269, and vol. xvi, 1903, p. 107.

† Cf. Loewinson-Lessing, op. cit., p. 368.

pressure have specific gravities varying between 2·60 and 2·65. There are good reasons for believing that plutonic pressures would not essentially affect these contrasts of density. Assuming a certain degree of fluidity in the magma (an assumption underlying the whole of this paper and believed to be demonstrated by such facts as the patent ease of diffusion that once reigned in each of the intrusives), it appears that blocks of the sedimentary rocks must sink in the magma, whether acid or basic.*

The actual shatter-breccias described by Bayley are therefore to be attributed to the last destructive effort of the magma, which, at that time, through cooling, had become too viscous to allow of the sinking of the xenoliths.

A precisely similar argument applies to the Moyie and Sudbury examples (see table of specific gravities and table in this Journal, vol. xv, 1903, p. 277). All these igneous bodies, though not intruded by magmatic stoping, yet show that process to have assisted in the production of the granites and granophyres. Whether this process has there been more or less efficaceous than molar or marginal assimilation, perhaps cannot be determined.

In all these cases the stoping that did occur must clearly have tended to destroy a simple chemical identity between igneous rock and country-rock at any given contact.

Summary.—It will be useful to review the chief field and laboratory observations so far noted as favoring the assimilation theory when applied to the granites and granophyres described in this paper.

1. Bayley's elaborate argument is believed to be valid except as it fails to take differentiation into account. No fact has been noted either by the writer in connection with the Moyie sill or in the descriptions of the other examples which tends to weaken that argument.

2. Belief in the truth of his conclusion is greatly strengthened by the repeated occurrence of essentially the same phenomena in widely separated regions.

a. At Pigeon Point, at Sudbury and on the Moyie River there occur intrusive bodies of gabbro passing by gradual transitions (as shown by chemical, mineralogical and specific gravity determinations) into the border phases of granite and granophyre. Both types of rock clearly belong to the same period of intrusion.

b. All three igneous bodies are of relatively great thickness, which means that, other things being equal, they possessed relatively great stores of thermal energy.

*Cf. R. A. Daly, op. cit., 1903, p. 277, etc.

c. In each occurrence the gabbro contains xenoliths of the more acid sedimentary rocks. These blocks are commonly more or less digested and the product of this local solution is always closely allied to, if not equivalent to, the granophyre-granite phase.

d. In each case there is correspondence though not equivalence between the composition of the acid border-phase and the average composition of the invaded formation. This important fact is emphasized in Tables I, II, III, IV and V, in which the silica and alkalies are either directly or inferentially seen to be more or less abundant in the granophyre-granite according to the relative abundance of those oxides in the respective country-rocks.

e. A considerable number of other examples not as yet thoroughly studied have been noted in British Columbia and Minnesota. The conditions are throughout identical or so allied as to favor one explanation common to all the occurrences.

f. The assimilation theory is also supported by certain other facts which have already been mentioned but merit a more detailed discussion such as is attempted in the sequel.

3. The principal objection to the doctrine of assimilation, namely, the objection that chemical analyses disprove any genetic relationship between intrusive and invaded formation at certain accessible contacts, cannot hold, because that objection allows no place for differentiation in the magma made compound by assimilation.

Asymmetry of the Intrusive Bodies.—There remains for particular explanation the cardinal fact that all the intrusive bodies are asymmetric. The granophyre-granite is always concentrated on one side of the intrusive, that is, along the upper contact or the side away from which the enclosing sediments dip.

In all the localities the dips of the sedimentaries and of the intrusive sheets are believed to have been flatter at the time of the injection of the magma than those dips now are. It is, indeed, possible that, in every instance, the gabbro sheet lay practically horizontal during the period of cooling and consolidation. In any case the granophyre-granites appears to have always overlain their respective gabbroid associates.

Three possible explanations have offered themselves for this asymmetry. (*a*) It is conceivable that extensive assimilation occurred only on the upper contacts; or (*b*) the asymmetry may be due to the density stratification of magma compounded of gabbro and digested sediments; or (*c*) due to a combination of both those factors.

One or more subordinate suppositions are necessary if the assimilation be credited essentially to the upper contact. On

the one hand, the invaded formations above and below the gabbro might be lithologically so different that the one above was much more subject to contact alteration than the one below. This idea is at once declared irrelevant in the British Columbia and Minnesota cases, where there is certainly no evidence of differences of digestibility.

On the other hand, it is possible that the original gabbro was differently constituted, and thus more energetic in assimilation, along the upper contact than elsewhere. Magmatic water or other strong solvents may thus be conceived to have early concentrated in the upper zone of each sill. In favor of this view would seem at first sight the fact that at Pigeon Point the zone of external metamorphism is reported by Bayley to be much wider on the upper contact than on the lower. (See fig. 4.) The same seems to be true in the Sudbury case, but is explained by Coleman as noted on a previous page. The writer could find no absolutely certain evidence of such differential metamorphism about the Moyie sill, yet considers it as probable.

That the conditions for the complete assimilation of the invaded formations obtained throughout the intrusive bodies is illustrated in the unmistakable digestion of xenoliths found at all depths in the gabbro. As already pointed out, the assimilation here belongs to the period immediately preceding the consolidation of the gabbro. A much greater volume of similar material derived from the interaction of gabbro and sedimentary rock must have been formed from other blocks in the hotter, more fluid, and more energetic magma of the preceding period. There seems to be no possible doubt that most of that material has diffused upward and now forms part of the granophyre-granite zone.

The simplest and most probable cause for that diffusion is, as suggested in the field hypothesis for the Moyie sill, the difference of density between the acid magma of assimilation and the enclosing gabbro.

It is quite possible that the metamorphosing effect of the new magma may have been greater than that of the original pure gabbro. The new magma would presumably carry with it the water derived from the digested sediments which, apparently in every case, are notably more hydrous than the original gabbro magma. The accompanying table shows the proportion of water (or loss on ignition) found in the analyses of the rocks of Pigeon Point.

Rock.	Per cent of water.
Gabbro	1·04
Intermediate rock	2·47
Red soda granite	1·21
Slate	3·24
Quartzite (loss on ignition)	1·88

So far as such water determinations in the crystallized rock can be considered as indicating a true condition of the magma before solidification, the table implies that the compound magma corresponding to the "intermediate rock" still held the extra water of assimilation up to the moment of crystallization; and, secondly, that the well differentiated magma corresponding to the soda granite had lost about half of the water of assimilation before final solidification. It is, accordingly, quite possible that this extra water which the upper acid zone could not hold in permanent combination, has been responsible for the unusual amount of external metamorphism in the sediments south of the Pigeon Point intrusive. Similar reasoning may apply to the Sudbury example, but the required elaborate chemical study of its more complex terranes has not yet been made.

In favor of this hypothesis is the fact that, so far as known to the writer, differential contact metamorphism of the kind here in discussion has never been described in connection with a sill that does not also show evidence of strong internal assimilation.

Finally, there is no cause yet well determined why water or other solvents should be systematically concentrated from the original magma along the roof of an intrusive sill. Such concentration may, indeed, be the rule, but it has apparently not been announced by any worker among the thousands of basic sills described in geological literature.

The conclusion seems justified that the special intensity of the metamorphism on the upper contact of certain intrusive bodies is probably not due to the special activity of solvents in the original magma along that contact. The explanation seems to lie partly in the different liability of the roof-rocks and floor-rocks to metamorphic change, but yet more in the metamorphic effects of water vapor set free in the digestion of the invaded hydrous sediments. This water vapor may have also assisted in the solvent work of the magma at the main upper contact, and, finally, in increasing the fluidity of that magma.

Magmatic Differentiation.—The development of basic, intermediate and acid zones in each of the sills is, thus, believed to have been the result of the density stratification of the compound magma of assimilation. The efficiency of differential density in separating out lighter acid material from the heavier basic, has been ably discussed and affirmed by Loewinson-Lessing.* It is unnecessary to recapitulate his argument, with which the present writer is in full accord.

* Op. cit., pp. 344–354.

Loewinson-Lessing points out that when large amounts of foreign rock-material is digested in a magma, there is established a special tendency toward a systematic differentiation of the mixture.* Liquation will then take place when the cooling mixture reaches a certain temperature. The same author also holds that, according to the principles of physical chemistry, a magma becomes actually more fluid as a result of digesting foreign material. Differentiation is thereby facilitated. Vogt's valuable researches tend to corroborate this view.†

The granites and granophyres of the Moyie sill, of the Pigeon Point intrusive, and of the Sudbury sheet are to be regarded as not directly or merely due to the contact solution of sedimentary rocks and schists by gabbro; they are controlled in their final composition by a common process of differentiation supplementary to the gravitative effect. At Pigeon Point the acid rock, whatever its structure and grain, is a rather definite mixture of oxides. This is illustrated in the analyses of granular soda granite, the "quartz keratophyre", and the porphyry of Little Brick Island near Pigeon Point.‡ For lack of sufficient analyses the same statement cannot be made concerning the Moyie sill, but within limits it applies to the huge Sudbury sheet.§

The acid zone may have won some of its soda from the original magma; the gabbro may now hold some of the potash with the silica derived from the micaceous and feldspathic quartzites and other sediments. It is obvious, however, that all the details of the chemical processes engaged in this type of magmatic separation (chemical affinity in magma disturbed by gravitative diffusion currents) cannot be worked out from existing data on the magmatic behavior of silicates.

The intermediate rock at all three localities may be regarded as occupying zones of incomplete differentiation.

Special interest attaches to the occurrence of the nickel ores along the lower contact of the Sudbury sheet. Barlow, Coleman, Vogt and Walker agree that these sulphides are soluble in magmas. The solubility is in inverse proportion to the acidity of those magmas.‖ The fact suggests that the sulphides have been precipitated from the norite which has been acidified by assimilation. The concentration of the ore on the lower contact is again the result of differentiation through contrasts of density, the sulphides settling to the bottom of the sheet. Loewinson-Lessing has already suggested this gen-

* Op. cit., pp. 375 ff.
† Op. cit., Part 2.
‡ Bull. 228, U. S. Geol. Surv., p. 89.
§ See A. P. Coleman, 1904 report, p. 213.
‖ J. H. L. Vogt, op. cit., p. 229.

eral hypothesis to explain the segregation of sulphide-ores, without, however, connecting the concentration with gravitative influence. Coleman has announced the view that the ores have thus settled to the bottom of the sill, but has not connected the action with the digestion of acid rock in the norite.* The whole array of facts connected with the Sudbury intrusive is so accordant with the double theory of assimilation and differentiation through density stratification, as to single out this particular case as perhaps, of all those noted in the present paper, the most convincing and illuminating.

It is necessary that brief reference be made to an alternative view of all these related phenomena. One may conceive that the granite-granophyre, intermediate rock and gabbroid rock in each of the intrusive sheets may be explained by simple differentiation from an *original* magma through density stratification but without the aid of significant assimilation of the country-rocks. Lack of space forbids that this hypothesis be here discussed at length. The writer believes that the hypothesis is untenable or, at least, is much less adapted to explaining the facts than the hypothesis of assimilation accompanied and followed by differentiation. Most of the facts on which that belief is founded have been already implied or expressly noted.

Among the significant facts are the following:

1. There is a close similarity in composition between the granite-granophyre zone and rims of manifest digestion about xenoliths now surrounded by gabbro. This consanguinity is inexplicable on the theory of mere differentiation within the original magma.

2. The genetic relationship between the granite-granophyre zone and the invaded sediments is further shown by certain special features already described among the structures of the acid rock in the Moyie sill, and of the overlying, metamorphosed quartzite. For example, the development of remarkably poikilitic quartz in the granite-granophyre and in the recrystallized quartzite (the quartz of the latter being largely or wholly indigenous) may be mentioned. This repeated occurrence of a peculiar structure finds no simple explanation on the pure-differentiation theory.

3. In the period of high temperature preceding the viscous period when the visible xenoliths were frozen in the gabbro, thousands or millions of other xenoliths were completely or in part digested in the gabbro magma. The product of their digestion can be found, apparently, in no other place than in the existing acid zone of each intrusive sheet.

* 1903 report, p. 277.

4. Mere differentiation of an original magma (through density stratification) cannot readily explain the slight but certain excess of silica along the lower contact of the Moyie sill. That degree of acidification is readily understood on the assimilation theory.

5. Along the British Columbia boundary a large number of contemporaneous gabbro sills of practically identical mineralogical and chemical composition have been found. In most of these no true granite-granophyre zone occurs. The composition of these gabbros is essentially equivalent to that of the gabbro in the central part of the Moyie sill; yet, on the pure-differentiation theory we should expect a distinct difference of composition between these other sills and the basic pole of differentiation in the Moyie sill. The assimilation-differentiation theory finds no difficulty in the essential equivalence of composition.

6. The assimilation-differentiation theory demands that a great absolute amount of thermal energy be credited to a sill in which secondary granite has been formed; that sill must always be thick. Other things being equal, granite formed by mere differentiation from an original magma should be found also in sills of less thickness, though here again the absolute thickness must be considerable. True granite with the relations described in this paper has never been found as a continuous zone in any intrusive sheet 500 feet or less in thickness. On the pure-differentiation theory it is difficult to understand why differentiation should afford true granite in a sheet of the strength observed at Pigeon Point, and should not afford a true granite zone in a sheet 400 or 500 feet thick. The assimilation-differentiation theory readily interprets the fact as due to the relatively enormous amount of heat required for the generation of the granite-granophyre zone, namely, an amount of heat characteristic only of thick intrusive sheets.

7. The pure-differentiation theory has to face another difficult question which does not arise if the assimilation-differentiation theory be accepted. Why was differentiation in the original magma postponed to the moment of intrusion? This difficulty is, of course, by no means conclusive against the pure-differentiation theory, but it means one more unavoidable theoretical burden weighting the pure-differentiation theory in a way which renders, by contrast, the assimilation-differentiation theory one of relative simplicity and, by so much, of greater strength.

General Application.—In the foregoing discussion the secondary origin of some granites has been deduced from the study of intrusive sills or sheets; but it is evidently by no means necessary that the igneous rock body should have the

sill form. The wider and more important question is immediately at hand—does the assimilation-differentiation theory apply to truly abyssal contacts? Do the granites of stocks and batholiths sometimes originate in a manner similar or analogous to that just outlined for the sills?

The writer has briefly noted general reasons affording affirmative answers to these questions.*

Gabbro and granophyre are often characteristically associated at various localities in the British Islands as in other parts of the world.† The field relations are there not so simple as in the case of the Moyie sill, for example, but otherwise the recurrence of many common features among all these rock-associations suggests the possibility of extending the assimilation-differentiation theory to all the granophyres. Harker's excellent memoir on the gabbro and granophyre of the Carrock Fell District, England, shows remarkable parallels between his "laccolite" rocks and those of Minnesota and Ontario.‡

At Carrock Fell there is again a commonly occurring transition from the granophyre to true granite, and again the granophyre is a peripheral phase. Still larger bodies of gabbro, digesting acid sediments yet more energetically than in the intrusive sheets, and at still greater depth, would yield a thoroughly granular acid rock as the product of that absorption with the consequent differentiation. This does not imply, of course, that all granites are of this origin, but it is quite possible that most intrusive granites are either of this origin or have been more or less modified through assimilation.

The difficulty of discussing these questions is largely owing to the absence of accessible lower contacts in the average granite body. All the more valuable must be the information derived from intrusive sills. The comparative rarity of such rock-relations as are described in this paper does not at all indicate the exceptional nature of the petrogenic events signalized in the Moyie, Pigeon Point or Sudbury intrusives. It is manifest that extensive assimilation and differentiation can only take place in sills when the sills are thick, well buried, and originally of high temperature. All these conditions apply to each case cited in the present paper. The phenomena described are relatively rare largely because *thick* basic sills cutting acid sediments are comparatively rare.

On the other hand, there are good reasons for believing that a subcrustal gabbroid magma, actually or potentially fluid, is general all around the earth; and secondly, that the overlying solid rocks are, on the average, crystalline schists and sediments

* This Journal, vol. xv, 1903, p. 269, vol. xvi. 1903, p. 107.
† See A. Geikie, Ancient Volcanoes of Great Britain, 1897.
‡ Quart. Journal Geol. Soc., vol. l, 1894, p. 311 and vol. li, 1895, p. 125.

more acid than gabbro. Through local, though widespread and profound, assimilation of those acid terranes by the gabbro, accompanied and followed by differentiation, the batholithic granites may in large part have been derived.* True batholiths of gabbro are rare, perhaps because batholithic intrusion is always dependent on assimilation.

The argument necessarily extends still farther. It is not logical to restrict the assimilation-differentiation theory to the granites. The preparation of the magmas from which syenites and diorites, for example, have crystallized, may have been similarly affected by the local assimilation of special rock-formations. The development of some of the anorthosites of the Canadian and Adirondack Archean was possibly conditioned on the digestion of part of the associated crystalline limestones by plutonic magma.

The officers of the Minnesota Geological Survey have shown that the same magma represented in the soda granite and granophyre of Pigeon Point forms both dikes and amygdaloidal surface flows.† The assimilation-differentiation theory is evidently as applicable to lavas as to intrusive bodies. But demonstration of the truth or error of the theory will doubtless be found in the study of intrusive igneous bodies rather than in the study of volcanoes either ancient or modern.

Finally, the fact of "consanguinity" among the igneous rocks of a petrographical province may be due as much to assimilation as to differentiation.

* Cf. R. A. Daly, op. cit.

† N. H. Winchell, Final Rep. Minn. Geol. Surv., vol. 4, 1899, pp. 519–22.

ART. XXIV.—*On Tychite, a New Mineral from Borax Lake, California, and on its Artificial Production and its Relations to Northupite;* by S. L. PENFIELD and G. S. JAMIESON.

Historical.—The new mineral to be described in this paper was discovered by the merest chance in 1895, when some minerals from Borax Lake, San Bernardino County, California, were being studied by one of the present writers (Penfield). At the time mentioned, word had been received from Mr. Warren M. Foote of Philadelphia that he had some unknown minerals from the Borax Lake region, and arrangement was made for their examination in the mineralogical laboratory of the Sheffield Scientific School. One of the minerals, which proved to be a new species, consisted of octahedral crystals, averaging about 3^{mm} in diameter, and concerning it Mr. Foote wrote that it was a carbonate of magnesium and sodium containing chlorine. The material sent for examination consisted of a large number of the octahedral crystals, and from amongst them a small one, which was perfect in form and seemed to be in every way typical of the lot, was selected for the purpose of making a few preliminary tests. It was brought in contact with a drop of nitric acid on a watch glass and dissolved with effervescence; the solution gave the flame test for sodium, a minute drop of it gave the reaction for magnesium with ammonia and sodium phosphate, but a test for chlorine with silver nitrate gave a negative result. Thinking over what else might possibly be present, the idea of a sulphate suggested itself, and a test with barium chloride indicated the presence of the SO_4 radical. Accordingly, a letter was sent to Mr. Foote informing him that there evidently was some mistake, for the mineral he had sent proved to be a sulphate and not a chloride. This elicited an immediate reply from Mr. Foote, stating that, on the contrary, the mistake was on our part, for he had always obtained the test for chlorine and had repeated the experiment with like results; thereupon the test was repeated by us, and the presence of chlorine was found in one crystal after another. The fact, therefore, was established, that in the material sent there were two minerals crystallizing in octahedrons, one containing the sulphate radical, the other chlorine, and that by chance a crystal of the rarer sulphate happened to be the one first selected for making the initial examination. A preliminary notice of the chlorine compound was published by Mr. Foote,* who named the mineral *northupite* after Mr. C. H. Northup of San Jose, California,

* This Journal (3), 1, p. 480, 1895.

who first observed the new mineral and supplied the material for investigation. A complete study of the chemical composition and physical properties of the new compound was subsequently made by Pratt, who found the composition to be $MgCO_3 . Na_2CO_3 . NaCl$, his results being published in this Journal.*

Being assured of the existence of a second, new, octahedral mineral, associated with the northupite, Mr. Foote generously responded to our request to send to New Haven his entire stock of crystals in order that a search might be made for the missing sulphate. The following simple method of testing was employed, which did not in any way injure the specimens: Some dilute nitric acid containing a little silver nitrate was prepared, and with a broom-straw a minute drop of the liquid was applied to each crystal. Thus, if chlorine was present, a little silver chloride would be formed and the drop of liquid would become milky-white. In testing several hundred crystals in this way, only two were found which did not give the reaction for chlorine. One of these was a small but perfect octahedron, the other a small cluster of octahedrons, of somewhat inferior quality: together they weighed only about 0·10 gram. It was hoped, however, that by sacrificing the specimens for chemical analysis sufficient determinations could be obtained for deriving the formula; but in this we were disappointed, for, unfortunately, the analysis met with an accident before a single determination had been made. We were thus compelled to abandon the hope of determining the composition of the new mineral until other crystals should be found in new lots of the northupite.

Recently our attention was called to the unknown sulphate by observing in the stock of Mr. Lazard Cahn of New York a supply of northupite crystals which he generously loaned to us for examination, but when tested they all proved to be the chlorine compound. Likewise Mr. Warren M. Foote of Philadelphia has been kind enough to send us his entire stock of northupite, consisting of something over four thousand crystals, among which we had the good fortune of finding one small octahedron, weighing but 0·0109 gram. Curiously enough, this was among the last ten crystals which were tested, and was found after hope of obtaining the desired sulphate had practically been given up.

Artificial production.—Believing that the unknown sulphate would prove to be closely related to northupite, and knowing that de Schulten† had succeeded in making the latter artificially, it occurred to us that possibly the wished for sulphate

* This Journal (4), ii, p. 133, 1896; also, iii, p. 75, 1897.

† Bull. Soc. Franc. de Min., vol. xix, p. 164, 1896.

might also be prepared synthetically. Following in general the method of de Schulten, 8 grams of Na_2CO_3 and 34 grams of Na_2SO_4 were dissolved in 120^{cc} of water, and to the solution 1·4 grams of $MgSO_4$ were added, which immediately produced an amorphoid precipitate, presumably of some basic magnesium carbonate. The mixture, contained in a flask, loosely stoppered to prevent evaporation, was then heated on a steam bath. By using chlorides in the place of sulphates, as described above, de Schulten succeeded in making northupite in a crystallized condition in about seven hours; in our experiment, however, we waited five days, the solution being heated without interruption, before any signs of crystallization appeared. In the meantime we had tried heating a similar mixture in a sealed tube at a high temperature, without definite results, and had practically given up hope of obtaining the desired crystals. It was almost a matter of accident, therefore, that the flask containing the mixture was left standing on the steam bath for so long a time. When the crystallization had once started, however, it apparently proceeded quite rapidly, and the insoluble material in the flask was almost wholly converted into octahedral crystals, very symmetrical in development and remarkably uniform in size, about 0·15^{mm} in diameter. Having once produced a crop of crystals, we are now able, by "seeding" or adding some of the product already formed to a new experiment, to produce crystals in fifteen hours, though it still seems to take several days to complete the reaction. When examined under the microscope, it was found that each crystal contained minute inclusions, presumably of basic magnesium carbonate, but the inclusions constituted a very small proportion of the total bulk of the material. The crystals were next suspended in acetylene tetrabromide, diluted with benzol, and it was found that they all floated when the specific gravity was 2·594, and on diluting to 2·583 almost all of the material sank. The mean of the two values, 2·588, may therefore be taken as the specific gravity of the mineral. It was found that the lighter crystals, left floating on the heavy solution, were preceptibly richer in inclusions than those which sank at 2·583. The crystals are quite hard and give a gritty sensation when ground in an agate mortar. They scratch calcite and probably, like northupite, have a hardness between 3·5 and 4. The crystals are isotropic when examined in polarized light. Using two surfaces which come together at the apex of an octahedron as a prism, it was possible to determine approximately the index of refraction, but the surfaces of the crystal were not good enough to make the determination accurate beyond the second place of decimals: the value found was 1·510, while n_y for northupite was 1·514.

An analysis of the purest material, separated by means of the heavy solution, gives the formula $2MgCO_3 . 2Na_2CO_3 . Na_2SO_4$, the results being as follows:

	I.	II.	Theory.
SO_3	15·08	15·06	15·33
CO_2	33·55	33·45	33·72
MgO	15·83	15·77	15·33
Na_2O	35·49	35·65	35·62
	99·95	99·93	100·00

The slight discrepancies between the results of the analyses and the theory are probably to be accounted for by the presence in all of the crystals of the minute inclusions mentioned on the previous page.

The finely powdered salt does not dissolve to any extent in hot water, nor does it suffer decomposition. Some powder, boiled with water for a considerable time, then filtered and dried, gave the following results:—SO_3, found 15·21 per cent, theory 15·33 per cent. The filtrate gave only a slight reaction of a sulphate when tested with barium chloride.

Name.—We have named the new and rare sulphate *tychite*, from τυχὴ, meaning luck or chance, a name which it well deserves, when it is considered that out of fully five thousand specimens examined, the very first crystal and one of the ten last crystals tested proved to be the sulphate, and only two other specimens were found, the ones lost in an unsuccessful attempt to make an analysis.

Comparison of the artificial salt with the natural mineral.—Without question, the artificial salt is identical with the mineral found at Borax Lake: they both contain the same constituents. They crystallize not only in the same system, but also in octahedrons. They are isotropic, although the last crystal of tychite found showed some slight action on polarized light, which seemed to be confined only to the exterior portions of the crystal, for fragments from the interior were wholly isotropic. The specific gravity of the artificial salt is 2·588, of the crystal examined by Pratt (the analysis of which was lost) 2·456, and of the last crystal found by us 2·30. The last crystal, however, contains numerous inclusions, which undoubtedly account for its low specific gravity. As far as can be recollected, the crystal examined by Pratt was very white and pure, but not equal in transparency to the artificial crystals. Both Pratt's determination, 2·456, and ours of the artificial salt, 2·588, are somewhat higher than the specific gravity of northupite, as might be expected from differences in composition: Pratt found the specific gravity of northupite to be

2·380, and de Schulten determined that of the artificial salt as 2·377. By using two of the faces which meet at the apex of the octahedron as a prism, we have succeeded in determining the index of refraction of the last crystal found. The surfaces of the octahedron were not very perfect, and had to be covered over for the most part, taking the reflections of the signal from only the tip end of the crystal, and the refraction of light through the same. The value obtained, n_y=1·508, compares favorably with that of the artifical salt, 1·510, especially when it is taken into consideration that the condition did not favor exact determinations in either case. A further argument for the identity of tychite and the artificial salt, if any is needed, is that at Borax Lake both tychite and northupite occur together, and were formed undoubtedly under similar conditions, while in the laboratory either of these closely related chemical compounds may be made by only varying the conditions of the experiment by using sodium sulphate for the one and sodium chloride for the other.

Of the four specimens of tychite thus far found, three have been very symmetrically developed octahedrons, but small, measuring not over 3^{mm} in diameter, and noticeably whiter than the average of the northupites. It is the small size of the crystals which favored the discovery of the new mineral, for in the original preliminary test one of the smallest and whitest specimens was selected, both because of its evident purity, and also with the idea of not using up any more material than was necessary. Those who may happen to have northupite crystals and wish to search for specimens of the new mineral, may look for tychite therefore among the smaller crystals. We are informed in a recent letter from Mr. Northup that the chances of finding additional crystals of tychite, or of the associated minerals, northupite and pirssonite, are too remote to be seriously considered, as the old borax works are now dismantled. Tychite, therefore, promises to be a very rare mineral, unless a new locality for it happens to be discovered. The single crystal which we recently had the good fortune to find, Mr. Foote has generously presented to the Brush Collection of the Sheffield Scientific School, and both for this gift and for the interest he has taken in assisting us in our investigation we take pleasure in expressing our most sincere thanks.

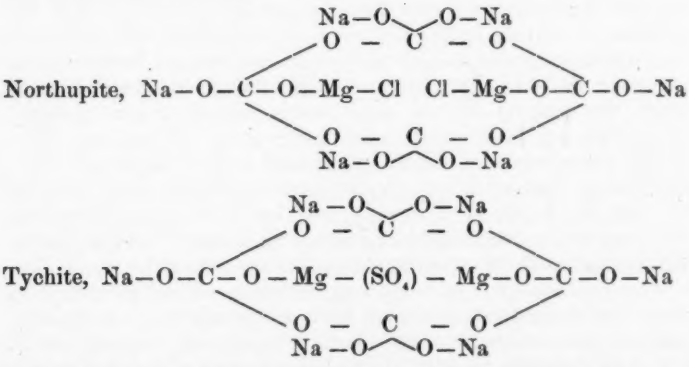
Comparison of tychite and northupite.—The two minerals, found so intimately associated with one another and both crystallizing in octahedrons, are chemically closely related, but in order to show the relation it is necessary to double the formula of northupite, as determined by Pratt. The compositions may then be expressed as follows :

Tychite, $2MgCO_3 . 2Na_2CO_3 . Na_2SO_4$.
Northupite, $2MgCO_3 . 2Na_2CO_3 . 2NaCl$.

Other physical properties are given below:

	Specific gravity.	Index of refraction, n_y.
Tychite,	2·456 natural. 2·588 artificial.	1·508 natural. 1·510 artificial.
Northupite,	2·380 natural. 2·377 artificial.	1·514 natural.

Theoretical.—There seems to be far more interest connected with the present investigation than the mere description of a new species. Although northupite is somewhat slowly soluble in cold water, and is quickly decomposed by boiling water with the separation of magnesium carbonate, tychite is almost insoluble, even when its fine powder is treated with boiling water. Unlike most insoluble substances, however, which precipitate quickly as soon as the constituents necessary for their formation are brought together, northupite and tychite are formed slowly. In de Schulten's experiment, northupite was obtained after seven hours heating, and in ours it took nearly as many days of continued heating to obtain crystals of tychite. It would seem as though the slowness with which these substances are formed might be taken as an indication of their having a complex molecular structure, and that the element of time is necessary for the arrangement of the atoms in a state of equilibrium. Just what the arrangement of the atoms is, we are not able to determine, but the simplest and most symmetrically developed formulas which suggest themselves are the following:



In these formulas the four carbon atoms are united by oxygen in ring formation, which it may be assumed it takes some time to establish, but, when once established, accounts

for the stability of the compounds. It is possible also that the assumed symmetrical arrangement of the atoms in the molecule is the cause of the crystallization of these compounds in the isometric system, for, as a rule, salts of a highly complex nature crystallize in some system other than the isometric. Moreover, if the above formulas are correct, it might be expected that tychite would be more difficultly soluble in water than northupite, for the SO_4 radical uniting the two magnesium atoms would serve, as we might say, to protect the latter from attack, while the sodium atoms could not be taken away without disturbing the equilibrium of the molecule. Perhaps also the union of the magnesium atoms by the SO_4 radical in tychite is more difficult to establish than the combination of the two chlorine atoms with magnesium in northupite, which may account for the greater length of time required to make the sulphate compound artificially.

In these compounds, two chlorine atoms in the one and a SO_4 radical in the other play the same rôle, and are isomorphous with one another in the broader sense of the term, namely, that different constituents may enter into similarly constituted molecules without changing the crystalline form. In simple chemical compounds, it is contrary to all experience that a chloride and a sulphate should have the same crystalline form, or be isomorphous with one another. In the salts under consideration, however, it is assumed that some definite arrangement of the large number of sodium, oxygen, carbon and magnesium atoms, by virtue of *mass effect*,* determines the crystalline form of the compounds, and that the rôles played by two chlorine atoms in the one and a SO_4 radical in the other are relatively so unimportant that either of these constituents may enter into the molecule without changing the crystalline form. Whether it is possible to obtain a single crystal containing both the two chlorine atoms and the sulphate radical replacing one another as isomorphous constituents, or to obtain a single crystal with a nucleus of one salt and an external growth, in parallel position, of the other, we are not as yet able to state, but experiments along these lines, to determine to what extent the principles of isomorphism may be applied to so widely different radicals as Cl_2 and SO_4 under the influence of mass effect action, will be carried on and form the subject of a later communication. In one experiment, in which the attempt was being made to obtain a product containing both Cl_2 and the SO_4 radical, a small crop of octahedral crystals was formed which reacted for neither chlorine nor sulphate. In appearance

*Compare *mass effect* action as applied to tourmaline (Penfield and Foote, this Journal (4), vii, pp. 122–124); also to the alunite-jarosite group of minerals (Hillebrand and Penfield, this Journal (4), xiv, pp. 216–220).

the crystals were in every respect like those of the artificial northupite and tychite. As seen with the microscope the crystals were full of inclusions, and, in forming, had evidently enclosed an unusually large amount of amorphous magnesium carbonate precipitate. We assumed at once, and correctly, that the compound would prove to be like northupite and tychite, except in having a CO_3 radical in the place of Cl_2 and SO_4, namely, $2MgCO_3 . 2Na_2CO_3 . Na_2CO_3$; see page 222. The analysis, made on a small quantity of the rather impure product, gave almost the theoretical percentage of CO_2, but the MgO was high and the Na_2O low, which was to be expected. Attempts will be made later to produce this salt in a state of purity, when it will be described more minutely.

Mineralogical Laboratory of the
Sheffield Scientific School of Yale University,
New Haven, Conn., July, 1905.

ART. XXV.—*A Modification of Victor Meyer's Apparatus for the Determination of Vapor-Densities;* by B. J. HARRINGTON.

THE ingenious apparatus devised by the late Professor Victor Meyer for the determination of vapor-densities has been in use for many years and has proved of great value for the purpose for which it was intended. It, however, has certain imperfections, being awkward on account of its height and very liable to be broken, especially in the hands of inexperienced workers. Two modified forms of the apparatus have been devised by the writer and have proved so useful in our own laboratories that it has been deemed worth while to publish a description of them. In both cases an attempt was made to simplify the apparatus and make it more convenient and rapid to work with.

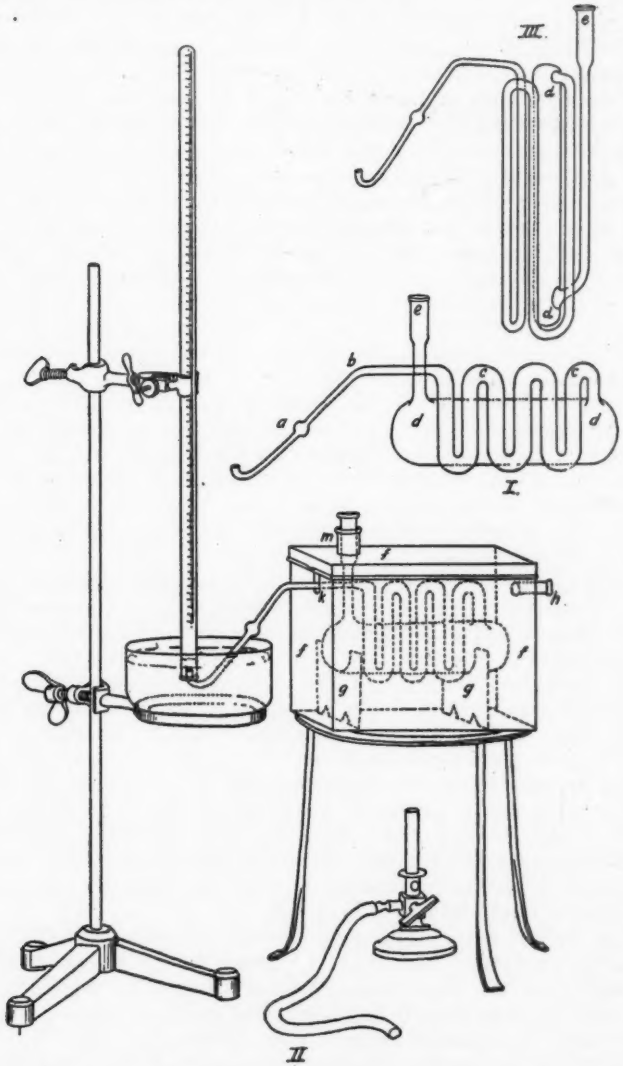
The first form tried is that shown as fig. I in the accompanying illustration. It will be observed that the receptacle *dd* is horizontal instead of vertical and that the long stem of Meyer's apparatus is bent upon itself a number of times; the apparatus accordingly occupying but little space. Instead of the long outer tube or jacket ordinarily employed, a box made of tinned iron or copper is used.

In making an actual determination the space around the glass at *m* and *k* (fig. II) is packed with a little asbestus, and it has been found advantageous to lay a piece of asbestus card on the cover of the box.

The weighed material in the ordinary stoppered tube or bulb is dropped in at *e* (fig. I) and as it has not far to fall there is no need of the usual cushion of asbestus or sand. As soon as one operation is completed the vapour is quickly swept out of the apparatus by connecting the tube *ab* (fig. I) with the vacuum-pump, the water in the box *ff* (fig. II) being kept continuously boiling. In this way one operation quickly succeeds another, and it has been found that students can make two or three determinations in the time required for one with the ordinary apparatus.

The second form experimented with is shown at III. In this the receptacle *dd* of I is placed vertically, as it was thought that the vapor would be less likely to be carried into the delivery tube than if the horizontal position were adopted. The tube *e* is somewhat longer than in the first form (I) but the curve at the bottom checks the velocity of the little tube containing the liquid and no asbestus is required at the bottom

of *dd*. Like No. I, this form is much more easily dried out than the ordinary apparatus. The metal box for No. III. is



not shown in the drawing, but its construction can be readily understood. With both forms of apparatus *e* was closed with

an ordinary cork, a correction being made for the small quantity of air displaced by the cork, but of course one of the improved appliances for introducing the liquid could be employed. So far the apparatus has been tried only for bodies with comparatively low boiling points, but it could no doubt be adapted for use with liquids with higher boiling points.

The following table gives a series of molecular weight determinations kindly made for me by Mr. Douglas McIntosh, D.Sc., of this university, with the different forms of apparatus, and gives an idea of the results which may be expected. Apparatus No. II. has, on the whole, been found to give more concordant results than No. I, but the latter is simpler and less likely to be broken than the former and in either case the figures obtained are sufficiently accurate for the purpose. They were obtained by working very rapidly and with no special precautions, and cannot therefore be fairly compared with those given by Victor Meyer's apparatus in the last column; for in the case of the latter Dr. McIntosh states that he took every precaution in order to ensure the most accurate results possible.

MOLECULAR WEIGHT DETERMINATIONS MADE BY MR. DOUGLAS MCINTOSH, D.Sc. (Air = 2 × 14·44)

	Modified Apparatus No. I.	Modified Apparatus No. II.	Meyer's Apparatus.
Methyl Alcohol CH_3OH (32)	35·0		
	36·0		
	36·9	32·9	
	36·5	33·4	
	34·0	33·5	31·91
	36·9	33·1	31·94
	34·7		
	34·8		
	37·2		
Mean	35·8	Mean 33·2	Mean 31·93
Methyl Alcohol C_2H_5OH (46)	46·0		
	43·1	44·1	
	45·0	44·7	46·70
	44·5	44·3	46·10
	43·6		
	42·3		
Mean	44·1	Mean 44·4	Mean 46·40

	Modified Apparatus No. I.	Modified Apparatus No. II.	Meyer's Apparatus.
Acetone	59·4		
CH_3	57·2		
CH_3 > CO	59·2	58·9	
(58)	58·0	59·0	57·90
	59·0	58·5	57 80
	59·1		
	Mean 58·6	Mean 58·8	Mean 57·85
Ether	76·1		
$(C_2H_5)_2O$	80·0		
(74)	82·6	77·7	
	74·9	75·0	75·70
	82·6	77·1	76·90
	76·1	76·2	
	Mean 78·7	Mean 76·5	Mean 76·30
Benzol	77·3		
(C_6H_6)	73·3	81·2	
(78)	80·2	80·8	79·00
	81·1	80·4	79·20
	81·7	79·7	
	Mean 78·7	Mean 80·5	Mean 79·10
Chloroform	134·9		
$CHCl_3$	131·5		
(119·5)	122·6		
	126·3	124·2	
	136·8	124·9	
	125·5	122·8	123·20
	125·8	126·2	123·00
	Mean 129·1	Mean 124·5	Mean 123·10

McGill University, May, 1905.

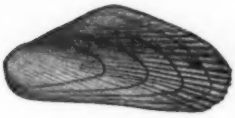


FIG. 1, × 1/1.

FIG. 2, × 2/1.

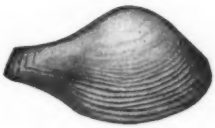


FIG. 3, × 2/1.

FIG. 4, × 2/1.

FIG. 5, × 2/1.

FIG. 6, × 2/1.

FIG. 7, 2/1.

FIG. 8, 2/1.

FIG. 9, 2/1.

FIG. 10, × 1/1.

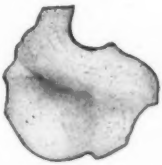


FIG. 11, 2/1.

FIG. 12, × 2/1.

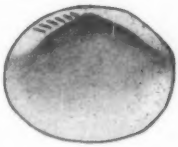


FIG. 13, × 2/1.

ART. XXVI.—*A New Lower Tertiary Fauna from Chappaquiddick Island, Martha's Vineyard;** by THOMAS C. BROWN. (With Plate VIII.)

CHAPPAQUIDDICK Island lies at the eastern end of Martha's Vineyard and owing to the shifting nature of the sands and varying tidal currents, it is at times connected with that island, but it is for the greater part of the time completely separated from it. Dr. Arthur Hollick has made a very careful study of the structure of this island and collections of the molluscs and plants found fossil upon it. The fossil plants have been very fully described by him in the Bulletin of the New York Botanical Garden, vol. ii, No. 7. The mollusc material has not been described and its horizon was provisionally set as Cretacic by Dr. Hollick because of the similar lithological character of this material with other deposits on Martha's Vineyard containing undoubted Cretacic fossils.

A careful study of the fossils has shown that this material is not Cretacic but Eocene in age and that it contains a new and peculiar fauna, a fauna which differs considerably from that of the Eocene deposits of the southern Atlantic slope.

In describing the deposits from which these molluscan remains were obtained Dr. Hollick says: ". . . the Island may be said to be composed of reassorted drift. . . . These hills in general may be described as kame-like, both in appearance and in composition. They are rounded accumulations of sand, gravel and cobble stones, with some bowlders, and were evidently formed by water action. In many places the sand and gravel is cemented together by limonite, forming hard lenses and strata, and ferruginous concretions and shaly fragments are abundantly represented."†

In his geological studies of Martha's Vineyard and surrounding islands Professor Shaler recognizes these ferruginous concretions and concerning them he says: "On the Island of Chappaquiddick and in the region near Edgartown, occasional fragments of a ferruginous sandstone are found which closely resemble in their general character the materials containing the Cretaceous fossils, but as they offer no organic remains I hesitate to consider them of that age."‡

Dr. Hollick considered these concretions as lithologically identical with those containing Cretacic molluscs and plants and set out to make a collection of organic remains that would

* The investigations on which this paper is based were carried on in the Paleontological Laboratory of Columbia University and the types of these species are in the university collection.

† Bull. N. Y. Botanical Garden, vol. ii, No. 7, p. 399.

‡ N. S. Shaler, 7th Ann. Report U. S. G. S., p. 326.

substantiate the point. "A systematic exploration of all exposures was therefore prosecuted; hundreds of the concretions and shaly fragments were broken open and critically examined and the result was a collection, not only of molluscs but also of plant remains, a few of which were found sufficiently well preserved for identification."*

Upon his return Dr. Hollick submitted the molluscs to Professor R. P. Whitfield of the American Museum of Natural History for a hasty examination, and concerning them Professor Whitfield spoke thus: "I have examined the fossils you sent the other day but I cannot satisfy myself as to their age. They consist of a *Modiola*, which apparently does not differ from our common *M. plicatula*, of the harbor here; an *Anomia* which might pass for *A. gigantaria* of the lower greensand marls of New Jersey, if it were not for the *Modiola*; also a single imperfect internal cast of a small (young?) *Pectunculus* not enough of it to tell the species, and a small bivalve of which I cannot yet determine the genus. These are the only shells I can recognize, and from their evidence I should think the rocks could hardly prove to be Cretaceous."†

These fossils were also submitted to Professor Grabau of Columbia University for examination. "Mr. Grabau is of the opinion that they may represent a new fauna, of more recent age than the Cretaceous, and this is quite consistent with the conditions under which they occur, so far to the south of any recognized Cretaceous outcrop. The character of the matrix also, with a single exception, is notably different from that in which undoubted Cretaceous molluscs have been found elsewhere, being a micaceous sandstone instead of a hardened clay or greensand."‡

A careful study and detailed comparison of these fossils with descriptions, figures, and specimens of the Cretacic and Eocene species shows that these fossils represent a new fauna of Eocene age. This fauna, however, differs widely from that of the Eocene deposits of the South Atlantic coast and seems to be more closely allied in general to the Eocene of England. Some of the specimens are very well preserved, while others are only represented by external and internal molds. Many of these molds are of such a nature and so well preserved that a wax impression can easily be taken and the characters of the fossil observed and compared. The following descriptions and comparisons include the best preserved and most typical specimens. Some of these are not perfect enough to be described as new species, but most of them can be generically placed.

* Bull. New York Botanical Garden, vol. ii, No. 7, pp. 399–400.
† Bull. N. Y. Botanical Garden, vol. ii, No. 7, p. 400.
‡ Ibid., p. 401.

Modiola vineyardensis sp. n. Pl. I, fig. 1.

Shell strongly ventricose, with a very prominent, almost angular umbonal ridge extending from the beak to the ventral margin. Shell distinctly concave anterior to this ridge; posterior to this ridge it becomes flattened toward the posterior margin; anterior end extremely short barely extending beyond the beak; posterior margin angulate, front margin nearly straight only a slight emargination occurring, basal end rounded; the portion of the margin from the end of the hinge line to near the point of angulation, and from beyond the point of angulation to the ventral margin, are almost straight lines. Surface with pronounced raised radii, flattened at the top and separated by spaces equal to or slightly wider than the radii; the radii are very fine and crowded on the anterior portion of the shell, much coarser on the median and posterior region, and distinct from the beak to the margin. They increase in size progressively from the dorsal to the ventral portion of the shell, with a corresponding increase in the width of the interspaces. They increase in number by intercalation as well as bifurcation. Fine distinct growth lines cross and cancellate the radii.

This species resembles *M. alabamensis* Aldrich,* from the Eocene of Maryland, but differs from it in general outline. It has a less curved anterior border and more radii, which are very distinct from the margin to the beak. The shell is shorter antero-posteriorly, and the posterior margin is more obtusely angulate. The shell of *M. vineyardensis* is also more ventricose and the umbonal ridge more angular and more pronounced.

In general outline this species approaches more nearly *M. grammatus* Dall,† from the Oligocene of Florida. The surface ornamentation is very similar, but judging from Dall's figure his shell is less ventricose and the umbonal ridge less angular and less distinct.

But even closer than to any of these is the resemblance of this species to *M. elegans* Sowerby‡ from the Eocene of England as figured and described by Wood among the Eocene bivalves. In general outline and surface ornamentation the resemblance is very close. *M. elegans* is, however, slightly less angulate at the postero-dorsal margin and judging from the figures is less ventricose.

Compared with the modern *M. plicatula* Lamarck, living along the Atlantic coast, *M. vineyardensis* seems to be nar-

* Bull. of Am. Palaeont., vol. i, p. 68, pl. v, fig. 13.
† Trans. Wagner Free Institute of Sci., vol. iii, pt. 4, p. 794, pl. xxx, fig. 2.
‡ Paleontological Soc. Monographs, London 1861–71. Eocene Bivalves, p. 65, pl. xii, fig. 5 (*c*).

rower toward the ventral portion of the shell, while the postero-ventral margin is more nearly a straight line and the radii are more numerous and finer and proportionately more widely separated. In *M. vineyardensis* and *M. plicatula* the mode of increase in the number of the radii by occasional intercalation and bifurcation is very similar. In *M. plicatula* the umbonal ridge is less angulate and less pronounced.

The shell described is a left valve with the following measurements: length 32·5^{mm}, width 14^{mm}. Several small specimens of this same species occur in other fragments of the concretions, as well as imprints of these shells. These smaller specimens correspond exactly with the growth lines of the younger stages in the larger individuals.

Modiola vineyardensis mut. *inornata.*

This mutation is very similar to the type of the species described above, except that the radii are very faintly marked. Fine, distinct, concentric growth lines mark the surface. Distinct radii can be seen on the anterior and umbonal region of the shell. These radii are flattened on top and separated by very narrow impressed lines. They fade out as they pass away from the umbonal and completely disappear on the ventral portion of the shell.

This mutation is represented in the collection by a comparatively small left valve.

Modiola Hollicki sp. n. Pl. VIII, fig. 2.

Shell ventricose, with a prominent umbonal ridge extending from the beak to the ventral margin; shell sloping abruptly to the anterior margin and becoming flat in the postero-dorsal part; anterior end rather short; anterior end rounded, front margin slightly arcuate, ventral margin broadly arcuate, rounded, postero-dorsal margin obtusely angulate; cardinal line straight; surface without ornamentation except for rather faint concentric lines of growth.

In general outline this species somewhat resembles *M. Mitchelli* Morris,* from the Eocene of England. It has a more obtuse postero-dorsal angle and is slightly narrower, with a slightly arcuate anterior margin instead of being emarginate as in that form.

Represented in the collection by two specimens, one nearly perfect left valve (fig. 2) and a valve lacking the beak and hinge area. These occur together with the Corbulas (see below) in a fine-grained hard ferruginous lutyte concretion quite different in character from the micaceous sandstone concretions in which all the other fossils are found.

* Palaeontological Society Monographs (see above), p. 68, pl. xiii, fig. 10.

Corbula Whitfieldi sp. n. Pl. VIII, fig. 3.

Shell large for the genus, ventricose and subtriangular; beak high and incurved; anterior margin sharply rounded, ventral margin broadly arcuate in the median and anterior portions but sinuously emarginate posteriorly; the posterior end of the shell is narrow, produced and abruptly truncated. Surface marked by distinct concentric asymmetrical folds or concentric wrinkles which are broadly rounded on top, with the dorsal border slightly broader and not as abruptly sloping as the ventral border. The folds are separated by narrow channeled interspaces. These folds constitute a surface ornamentation, and not lines of growth, as is shown by the fact that they increase in number by intercalation, some folds extending from the anterior to the median portion of the shell, while others extend almost to the posterior end. The principal folds extend to the posterior end and are there sharply flexed. These folds are well defined on the ventral half of the shell and become finer and more crowded on the umbones and almost disappear at the beaks.

This species approaches very closely in general outline and surface ornamentation to *C. alaeformis** Gabb, from the Tejon formation of California, but is less than one-half as large. The concentric folds become finer and more crowded on the umbonal region in the specimen from Chappaquiddick than in that figured by Gabb.

This species also somewhat resembles *C. subenqonata*† Dall, from the Eocene of Maryland and Virginia, but differs from that species in being narrower anteriorly and more produced posteriorly, and in the absence of a subcarinate ridge extending from the umbo to the posterior margin. The concentric folds are also more crowded and less prominent on the umbonal region.

The material in hand represents a right and a left valve. These specimens occur in a very fine-grained hard ferruginous lutyte concretion, quite different in character from the material in which most of the other fossils are found.

Anomia simplexiformis sp. n. Pl. VIII, fig. 10, 11.

Shell subovate and prolonged in the region of the beak; left valve very globose, nearly equilateral, somewhat irregular; beak located in median dorsal portion of the shell, submarginal, slightly projecting and incurved; surface without plications or ornamentation, except possibly very faint indications of concentric lines of growth.

* Palaeontology of California, vol. ii, p. 177, pl. xxix, fig. 63.
† Md. Geol. Sur., Eocene, p. 163, pl. xxxii, figs. 1, 1a, 2, 2a, 2b.

A portion of a right valve, probably of this species, is present in a fragment of the ferruginous concretion (fig. 11). It is very much flattened, more or less irregular, with large byssal opening and indications of very faint concentric growth lines.

This species is represented by several complete or nearly complete left valves, varying greatly in size, the length ranging from ten to thirty millimeters. It resembles very closely the modern *A. simplex* from the shores of Long Island. It has the same general outline and shape, and approaches that species in size and in the absence of surface plications and other ornamentations.

Anomia paucistriata sp. n. Pl. VIII, fig. 12.

Shell subcircular, somewhat irregular; left valve convex, nearly equilateral; beak submarginal, dorso-medially placed and not pronounced; surface marked by a few faint radiating striations, crossed and cancellated by very fine concentric lines of growth.

This species is smaller than the preceding, averaging in length about ten to twelve millimeters. It is represented by several left valves. Right valve unknown.

Glycymeris sp. ?. Pl. VIII, fig. 13.

Represented by several internal molds not preserving characters sufficient for specific description. The figure shows the internal characters of the shell and is drawn from a wax imprint made from a mold.

This species is smaller and more ovate in form than *G. idoneus* Conrad, from the Nanjemoy and Aquia formations of Maryland. In size, form and general appearance it resembles more closely *Glycymeris (Pectunculus) decussatus* Sowerby, from the Eocene of England.

Nucula sp. ?.

Represented by a few small internal molds. In one at least the dental characters are very well preserved. In general outline these resemble very closely *N. potomacensis* Clark, from the Eocene of Maryland, but do not preserve sufficient characters for specific identification or description.

Turritella sp. ?. Pl. VIII, fig. 4.

Shell small, spire high, angle about twenty-five degrees each whorl marked by a distinct, well-defined anterior and less prominent posterior spiral carinate ridge, following around above and below the suture, otherwise the surface is smooth and free from ornamentation; suture distinct; whorls closely placed and rapidly increasing in size.

This species resembles very closely a Turritella not specifically identified from the Eocene of Whellock, Texas, in the University collection. The Whellock specimen is larger but has the same apical angle, is free from ornamentation and has the anterior and posterior carinate ridges present but faintly marked.

This description is based on a wax imprint made from a very perfectly preserved external mold in a red micaceous sandstone concretion. The full length of the shell is not represented, so that the number of whorls and dimensions cannot be given. There are no characters of aperture and lips apparent.

Terebra sp. ?. Pl. VIII, fig. 5.

Shell elongate, spire elevated, whorls closely placed, rapidly enlarging, flat on the outer surface between suture, free from ornamentation or with very faint revolving lines, aperture elongate elliptical, pointed anteriorly, rounded posteriorly; outer lip thin and broadly arcuate, inner lip smooth without callus or ridge.

The specimen figured occurs on the edge of a small fragment of rock. The apex is concealed in the matrix and the anterior end of the aperture is slightly injured so that it does not show the minute characters.

Terebra juvenicostata sp. n. Pl. VIII, fig. 6.

Shell small and slender, spire elevated; apex pointed, acute with an apical angle starting at about thirty degrees and decreasing toward the body whorl where the sides of the spire approach to parallelism; the whorls are closely placed and flattened between the sutures. There are distinct ribbings on the earlier whorls which become less distinct along the advancing spire and disappear on the body whorl.

Odostomia semicostata sp. n. Pl. VIII, fig. 7.

Shell small, consisting of six or seven volutions, spire elevated, apical angle thirty degrees; sutures very pronounced; volutions flattened convex between sutures; earliest whorls marked by distinct transverse plications or ribs which become almost or quite obsolete on body whorl; outer lip distinctly denticulate within.

The aperture and columella of this specimen is not fully preserved so it cannot be accurately described. Length of shell as preserved $9{\cdot}5^{mm}$.

Odostomia crenulata sp. n. Pl. VIII, fig. 8.

Shell very small, spire high and closely coiled, apex subacute, whorls flattened externally, faintly crenulate along the posterior margin, suture distinct, aperture and lips unknown.

Genus? sp.? Pl. VIII, fig. 9.

Shell small, loosely coiled, apex acute, whorls five or six, well rounded, rapidly increasing in size, smooth without any ornamentation: suture quite deep and distinct, character of aperture and lips unknown.

This species is very similar to a *Limnaea* in shape but can hardly be one of these as it appears to be a salt water form.

Represented in the collection by a small but very perfect external mold of which a wax impression was taken.

Ostrea sp.?

Several small internal molds of representatives of this genus are present among the fragments of the concretion. These are not sufficiently well outlined to be specifically determined. They seem to represent at least two or three different species and all are comparatively very small.

Cardium? sp.?

Several casts doubtfully referred to this genus are to be found among the fragments of concretion collected by Dr. Hollick.

These fossils represent a new and distinct fauna markedly different from that of any other Eocene deposits of this country. Since this fauna does not contain a single species in common with the Eocene faunas of the Atlantic slope and gulf deposits, it cannot be accurately correlated with these beds and assigned its proper place in the geologic scale. Nevertheless from the general characteristics of the contained species and their affinities to forms from widely distant provinces, the horizon of these deposits can be ascertained with some approximation to the truth.

Considering the marine Eocene deposits of this country as a whole, we find that they naturally fall into several provinces lithologically quite distinct, and containing faunas with very few species in common. In New Jersey there is a small and isolated area known as the Shark River beds from their outcrop along that river. According to Clark, these beds represent lower Eocene and rest conformably upon the Cretacic below. By early writers they were considered a part of the Cretacic, as there was no marked line of separation between them and the underlying strata. The fossils, however, were found to be of undoubted Eocene character, and although the fauna was lacking in some of the most widely distributed Eocene species, it still contained no characteristic Cretacic forms.

These Shark River deposits were thought by Harris to represent a higher horizon than the Eocene deposits of Maryland

and Virginia, and Dall, in his correlation tables of the North American Tertiaries, has placed them in the Claibornian stage or equivalent to upper Middle Eocene. The fossils of this province differ so widely from those of the regions immediately to the south that correlation is very difficult, and even now there is doubt as to the exact position of these beds.

A second province of the Eocene, generally known as the Pamunkey formation from its typical development along the Pamunkey River in Virginia, begins in Delaware and extends across Maryland well into Virginia. Lithologically these deposits have more similarities to those of the provinces to the south than to the Shark River beds of New Jersey, yet they are sufficiently distinct both lithologically and in their contained fauna to require complete separation. According to Clark these deposits "constitute a single geological unit."

A third province embraces the Eocene deposits of the Carolinas and Georgia and affords a far more complete series of Eocene strata than either of the more northern areas. The lower beds consist of arenaceous and conglomeratic deposits, rather sparingly fossiliferous, probably because the material by its very nature was not adapted to permit the preservation of fossils. The middle and upper beds are well developed and represented by limestones and marls containing an extensive fauna, yet quite distinct from the surrounding provinces.

A fourth, the Gulf province, is by far the most extensive of the Eocene areas. It extends from Florida to Texas and includes the so-called Mississippian embayment, an area extending well up into the Mississippi basin. All stages of the Eocene are more fully represented, but both lithologically and paleontologically this province is very distinct from those along the Atlantic coast. Peculiar conditions in this area resulted in the interbedding among the other deposits of many lignitic strata.

A fifth marine Eocene province occurs along the Pacific coast, and outcrops along the coastal range in California, Oregon and Washington. These deposits are generally known as the Tejon group and were originally referred to the Cretacic. Later study has shown them to be of Eocene age, and yet their fauna differs widely from those of the Atlantic and Gulf provinces.

The fauna from Chappaquiddick represents a new and distinct Eocene province, differing from all the other provinces but no more widely different from these than they are from one another. Although in this fauna there are several species somewhat resembling those of the provinces to the south, on the whole it would seem to be more closely allied to the Eocene of England. The genera most abundantly represented

in these Chappaquiddick deposits, e. g., *Modiola*, *Glycymeris*, are also among the most abundant in the English deposits. These same genera, although represented in the Atlantic and Gulf provinces, are there more sparsely distributed and occur with other more abundantly represented genera that appear to be altogether wanting in the Chappaquiddick deposits.

A comparison of this Chappaquiddick fauna with other Eocene faunas indicates that it is of lower Eocene age, the species most closely resembling those found in this fauna being found in the lower beds of the Atlantic and Gulf provinces, the Tejon of California and the lower beds of England. These deposits may possibly be of the same age as the Shark River beds of New Jersey, but being deposited in a region separated from this have no forms in common with it, but such correlation could be only conjecture. As the correlation of the well known Eocene deposits is even yet very uncertain, it is unnecessary and impossible to place these beds any more definitely than simply to say they are lower Eocene.

Columbia University, New York City.

EXPLANATION OF PLATE VIII.

FIGURE 1.—*Modiola vineyardensis* ..... p. 232
FIGURE 2.—*Modiola hollicki* ..... p. 232
FIGURE 3.—*Corbula Whitfieldi* ..... p. 233
FIGURE 4.—*Turritella* sp. ? ..... p. 234
FIGURE 5.—*Terebra* sp. ? ..... p. 235
FIGURE 6.—*Terebra juvenicostata* ..... p. 235
FIGURE 7.—*Odostomia semicostata* ..... p. 235
FIGURE 8.—*Odostomia crenulata* ..... p. 235
FIGURE 9.—Genus ? sp. ? ..... p. 236
FIGURES 10 and 11.—*Anomia simplexiformis* ..... p. 233
FIGURE 12.—*Anomia paucistriata* ..... p. 234
FIGURE 13.—*Glycymeris* sp. ? ..... p. 234

Art. XXVII.—*The Production of Radium from Uranium;* by Bertram B. Boltwood.

The hypothesis that radium is a disintegration product of uranium has been greatly strengthened through the demonstration of the fact that in radio-active minerals the quantity of radium is directly proportional to the quantity of uranium present.* On the basis of the disintegration theory a proportionality of this sort is to be expected between the parent element and its radio-active successor.

Additional data on this highly important question are however desirable, and a single experiment likely to further elucidate the problem has been independently undertaken by a number of different investigators. This experiment consists in observations conducted on a carefully purified uranium salt with a view to determining whether, with the lapse of time, measurable quantities of radium will be produced within it. If radium is a *direct* product of uranium through the intermediate stage of uranium-X and if the average life of radium is approximately 1,000 years, then it can readily be deduced that, with the delicate methods of measurement at command, the quantity of radium formed in a few hundred grams of uranium salt will be readily detectable and measureable after the lapse of a period no longer than a month. If, however, one or more transition products of a relatively slow rate of change intervene between the substance uranium-X and radium, the production of radium will be so protracted that no quantity of it sufficiently great to permit its detection will be formed within a greatly extended period.

The difficulties involved in the experimental demonstration of the growth of radium do not appear to be great. Uranium forms no radio-active, gaseous disintegration product, while the radium emanation affords a most convenient means of quantitatively estimating any radium which may be present. A solution of a carefully purified uranium salt can therefore be prepared and can be tested at intervals for radium emanation. If radium is formed from the uranium its existence will be indicated by the presence of radium emanation in the uranium solution.

Three papers in which an experiment of this character is described have been published by Mr. Soddy.† In the first

* Boltwood, Phil. Mag. (6), ix, 599; Strutt, Proc. Roy. Soc. Lond., lxxvi, 88; McCoy, Berichte d. deutsch. chem. Ges., xxxvii, 2641.

† "The Life-history of Radium," Nature, lxx, 30; "The Origin of Radium," Nature, lxxi, 294; "The Production of Radium from Uranium," Phil. Mag. (6), ix, 768. Mr. Whetham has also published two contributions on the same general topic (Nature, lxx, 5; *ibid.*, lxxi, 319) in which he states

paper, published May 12, 1904, very scanty details of the experimental procedure are given, but a summary of the conclusions reached at that time by the author is as follows:

1. The quantity of radium which has accumulated in one kilogram of uranium nitrate in twelve months is less than 10^{-11} gram.

2. The question so far as the production of radium *from uranium* is concerned is practically settled.

3. If uranium changes into radium, less than one ten-thousandth part of the theoretical quantity is produced during the first year's accumulation.

4. The evidence may be taken as indicating that uranium is not the parent element of radium.

The second paper, published Jan. 26, 1905, eighteen months from the commencement of the experiment, is likewise lacking in a detailed account of the experimental methods, but the author states that measurements carried out at that time with the kilogram of uranium nitrate under observation indicate that it contains $1{\cdot}5\times10^{-9}$ gram of radium, a quantity which, while of considerable relative magnitude, is only one five-hundredth of the amount to be expected from the disintegration theory on the assumption of a direct change. The author suggests that the greater part of the radium emanation may (under the conditions of the experiment) be retained in the uranium solution and not evolved as a gas. On the basis of the amount of radium assumed to be then present it is deduced that the fraction of uranium changing per year is 2×10^{-12}.

After pointing out certain sources of error likely to have exercised a disturbing influence during the elapsed period of observation, the author adds,—"if the whole series of measurements from the commencement are recalculated, eliminating the error alluded to, they are fairly consistent with there having been a steady production of radium at this rate continuously from the commencement." One of the sources of error alluded to was the introduction of very considerable quantities of radium salts into the laboratory during the period when the kilogram of uranium nitrate was under observation. It is stated that the presence of this radium greatly disturbed the electroscope in which the measurements were conducted. Additional difficulty had been previously experienced in attempting to standardize the measuring instrument with the emanation corresponding to a known weight of pure radium salt.

that he also believes that he has observed indications of the growth of radium in uranium compounds. Since Whetham's communications contain neither any account of experimental details nor any record of quantitative measurements, it is impossible to judge as to the value of the data on which the author's conclusion is based.

The third and more elaborate article by the same author appeared in the June number of the Philosophical Magazine. The data briefly given in the earlier articles are here treated at greater length and a closer insight can be gained of the experimental methods and the results on which the author's later conclusions are based. Although it is stated in this paper that observations had been taken occasionally over a period of eighteen months and that these observations indicated a *gradual* growth of the emanating power of the uranium solution, the only definite and directly comparable numbers are restricted to a total period of about three weeks (Dec. 17, 1904 to Jan. 9, 1905) and include only four measurements conducted at the close of the period of observation.

Without entering into a discussion of various minor details in Mr. Soddy's papers, it is desired to call particular attention to the following important considerations in relation to the experimental data submitted:

First. No conclusive evidence is brought forward to show definitely how much or how little radium was present in the uranium solution at the commencement of the experiment.*

Second. It appears extremely possible that the increase in the content of radium which Mr. Soddy believes he has observed in his uranium solution may in fact have been due to the accidental and unconscious introduction of radium salts during the tests conducted at the end of the twelve months period. According to his own statements these tests were carried out in a laboratory notably contaminated with various radio-active products, and the accidental introduction of the sub-microscopic quantity of material ($1{\cdot}6\times10^{-9}$ gram.) which was afterwards detected would account for the later positive results. The liability of contamination from an extraneous source is strongly suggested by the behavior of Mr. Soddy's electroscope, in which the normal air leak has risen from 0·048 division per minute to 1·56 division per minute, an increase of over thirty times, during the period covered by his experiments.

The conditions essential to the elucidation of the question of the actual production of radium in uranium compounds would seem to be:

* The writer of the present paper convinced himself at the beginning of his own experiments that the method of procedure followed by Mr. Soddy in testing his solutions for radium emanation is entirely unsuited for the determination in question. A concentrated solution of incompletely purified uranium nitrate containing traces of radium gave up only a fraction of the total radium emanation generated within it when the solution was allowed to stand for days in contact with a small air space and air was bubbled through it. It was speedily found that only by boiling the solution vigorously for about fifteen minutes could the total emanation present be positively separated.

(*a*) The employment of a method for the determination of radium which gives positive and quantitative results. The method must be suitable for the determination of very small quantities of radium and must be capable of indicating the *maximum* quantity present at all times.

(*b*) The preparation of a pure compound of uranium and the demonstration that the compound is initially free from radium.

(*c*) Proper conditions for testing and preserving the uranium salt in order to preclude the introduction of radium or radium emanation from external sources, so that if the presence of radium is noted it can be assumed with certainty that the radium found has actually been formed in the solution.

It would appear that none of these essential conditions has been fulfilled in the experiment described by Mr. Soddy.

The writer of the present paper has been conducting an experiment on the growth of radium in a uranium solution for the past thirteen months. The conditions of the experiment were the following: In May, 1904, a kilogram of "purest uranium nitrate" was purchased from Eimer & Amend of New York City. This material was tested qualitatively for radium (through the emanation) and readily detectable quantities of this element were found to be present. The salt was dissolved in distilled water and the solution was filtered. The compound was then recrystallized five separate times, the conditions being so chosen that the separate crystals of each of the different crops were not over two millimeters in cross-section. The mother liquors were each time removed from the crystals on a suction filter, and the crystals were washed with a small quantity of ice-cold water.

The final yield of purified material was a little in excess of 200 grams. Of this 100 grams were taken and dissolved in pure, distilled water. This solution was introduced into a glass bulb with a capacity of approximately 400^{cc}, diluted to about 250^{cc}, and the neck of the bulb was drawn out into a short capillary and sealed in the flame of the blowpipe. The solution was sealed up on July 8, 1904. Thirty days later the bulb was opened under conditions which precluded the escape of any portion of the contained gases and the entire gaseous contents were removed and transferred to an electroscope. In order to completely displace the dissolved gases and any radium emanation which might have been present the solution was boiled vigorously for about fifteen minutes.*

*The removal and collection of the gaseous contents of the bulb was accomplished by the use of the apparatus which has been described in a previous paper (this Journal, xviii, 379). The neck of the bulb containing the uranium solution having been first notched with a file, it was inserted in the rubber tube D, the point was broken off within the tube, and the gases displaced from the bulb on heating were collected in the burette D, which was filled at the start with boiling water.

The type of electroscope used in this investigation has already been described (this Journal, xviii, 97). The emanation from the radium associated with 0·1 gram of uranium in a radio-active mineral caused a leak of approximately 21 divisions per minute. Assuming that the 100 grams of uranium nitrate contained 48 grams of uranium, the leak corresponding to the quantity of radium in radio-active equilibrium with 48 grams of uranium would be approximately 10,000 divisions per minute. The normal air leak of the instrument was 0·012 division per minute, and an increase of 0·005 division per minute could have been detected with certainty. The electroscope was therefore capable of indicating the presence of a quantity of radium equal to 5×10^{-7} of the equilibrium quantity. The actual quantity of radium equivalent to a leak of 0·005 division per minute was $1{\cdot}7\times10^{-11}$ gram.*

On introducing the gases present† in the uranium solution into the electroscope *no increase* in the leak of the instrument could be detected although the observations were continued over a period of eight hours. The quantity of radium present at the start was therefore less than $1{\cdot}7\times10^{-11}$ gram.

The uranium solution in the bulb was allowed to cool, and the neck of the bulb was again sealed. At the end of six months from the start, in January, 1905, the uranium solution was again tested under conditions identical with those under which the first test was carried out. Entirely negative results were obtained and the quantity of radium then in the solution was still less than $1{\cdot}7\times10^{-11}$ gram. A similar test was conducted on August 2, 1905, 390 days from the commencement, and no evidence of the presence of radium emanation was even then obtained. It can therefore be positively stated on the basis of sound experimental data that in 390 days the quantity of radium formed from 48 grams of uranium in a uranium nitrate solution is less than $1{\cdot}7\times10^{-11}$ gram.

The quantity of radium which can have been produced in the given time is therefore less than one two-millionth of the equilibrium quantity and less than one sixteen-hundredth of the quantity which would be expected from the disintegration theory if the value of λ for radium is taken as $8{\cdot}8\times10^{-4}$ $(\text{year})^{-1}$.‡ The quantity is furthermore only about one-tenth of the quantity assumed by Mr. Soddy to have been formed from an equal quantity of uranium in his solution during an interval of eighteen months.

It is important to add that the whole series of measurements has been conducted in a laboratory which has been carefully

* Rutherford and Boltwood, this Journal, xx, 55.
† At the end of the 30-day period.
‡ Rutherford, Trans. Roy. Soc. London, (A) cciv, 215.

protected from contamination by the salts of radium or other radio-active substances, and that the electroscope used has been reserved for this particular research, its original normal air-leak having remained unaltered throughout the entire period. It has therefore been unnecessary to introduce any corrections or to make any allowances for possible errors due to known causes of any description.

The experiments described in this paper are considered to indicate that the results obtained by Mr. Soddy are without significance and that one or more products of a slow rate of change intervene between uranium and radium.

It is claimed, moreover, that the conclusions in Mr. Soddy's first paper, so far as they relate to the *direct* transformation of uranium into radium, are more truly in accord with the actual facts than are those contained in his later publications.

139 Orange street, New Haven, Conn.
August, 1905.

SCIENTIFIC INTELLIGENCE.

I. Geology.

1. *Explorations in Turkestan with an account of The Basin of Eastern Persia and Sistan. Expedition of 1903, under the direction of* Raphael Pumpelly. 4to, 324 pp., 6 pls., 174 figs in text. Washington, D. C. (Published by the Carnegie Institution of Washington. Publication No. 26. April 1905.)—This publication contains the following five papers: Archeological and Physico-Geographical Reconnaissance in Turkestan by Raphael Pumpelly; A Journey across Turkestan by William M. Davis; Physiographic Observations between the Syr Darya and Lake Kara Kul, on the Pamir, 1903, by Raphael W. Pumpelly; A Geologic and Physiographic Reconnaissance in Central Turkestan, by Ellsworth Huntington; The Basin of Eastern Persian and Sistan, by Ellsworth Huntington.

Professor Pumpelly states in the introduction that "At the end of 1902 the Carnegie Institution voted a grant to me 'for the purpose of making, during the year 1903, preliminary examination of the Trans-Caspian region, and of collecting and arranging all available existing information necessary in organizing the further investigation of the past and present physico-geographical conditions and archeological remains of the region.'

"The investigation was proposed because (1) there is a school that still holds the belief that central Asia is the region in which the great civilizations of the far East and of the West had their origins; and (2) because of the supposed occurrence in that region, in prehistoric times, of great changes in climate, resulting in the formation and recession of an extensive Asian Mediterranean, of which the Aral, Caspian, and Black seas are the principal remnants.

"It had long seemed to me that a study of Central Asian archeology would probably yield important evidence in the genealogy of the great civilizations and of several, at least, of the dominant races, and that a parallel study of the traces of physical changes during Quaternary time might show some coincidence between the phases of social evolution and the changes in environment; further, that it might be possible to correlate the physical and human records and thus furnish a contribution to the time scale of recent geology.

"At my request Professor William M. Davis assumed charge of the physico-geographical part of the preliminary reconnaissance."

In concluding he remarks that "We have shown that the recent physical history of the region is legibly recorded in glacial sculpture and moraines, in orogenic movements, in valley cutting and terracing, in lake expansions, and in the building up of the

plains, and we have made some progress in correlating these events.

"We have also found full confirmation of the statements as to a progressive desiccation of the region of long standing, which has from a remote period continually converted cultivable lands into deserts and buried cities in sands.

"We have found, widely distributed, great and small abandoned sites of human occupation, with evidences of great antiquity.

"We have reason to think that a correlation of these physical and human events may be obtained through a continuance of the investigation, and that archeological excavations will throw light on the origin of Western and Eastern civilization."

In the second article Professor Davis describes his observations upon the Caspian region with its abandoned shore lines up to 600 feet above the present water-level, and the traces of the Pliocene sea whose deposits, as the Russian geologists have shown, underlie the plains of southern Turkestan. He says of the Piedmont plains that: "Since the withdrawal of the Pliocene sea, the eastern and southern borders of the plains of southern Turkestan appear to have been aggraded by the rivers that flow out upon them from the mountains. That a certain measure of such constructive action has taken place is announced by the Russian geologists, but it is not apparent that the full measure of river action has been recognized. Some of the strata of the plains are said to be not fluviatile but lacustrine, because they are of fine texture and uniform structure, without the variable layers of gravel that are by implication supposed to be always indicative of river work; but this seems to be a simpler solution than the problem deserves. There are many rivers that do not carry gravel, and there are many river plains whose smooth surface must receive very even and uniform deposits of flood-laid silts over large areas. Records of boring are quoted by Walther which show river muds on sand and loess to a depth of nearly 50 meters beneath the bed of the Amu River at Charjui, where the great railroad bridge was built. The record of a well boring at Askhabad, quoted by the same author, shows variable piedmont deposits over 2,000 feet deep. It seems, indeed, as if we had in the plains of Turkestan and the Great Plains of our West one of the most striking of the many physiographic resemblances between Eurasia and North America; and that there as well as here an increasing share may be given to the action of aggrading rivers in forming the plains, as observations are extended. It is well known that the tide of geological opinion in this country has in recent years turned more and more toward a fluviatile origin for the strata of the Great Plains that slope eastward from the Rocky Mountains, and the traditional lacustrine origin of the plains strata has been repeatedly questioned; so we may expect, as closer attention is given to the details of river-laid formations, that a larger and larger share of the fresh-

water strata that slope westward from the mountains of Central Asia may be interpreted as fluviatile rather than as lacustrine."

"The irregular structure of the piedmont slope, as exposed in cuts along the railroad line, is well described by Walther. There is a frequent and irregular alteration of stratified or massive loess-like clay, finely stratified sands, and coarse gravel, with many local unconformities; all this being the result of the variable action of floods that sweep suddenly, unguided by channels, down the piedmont slope; now eroding, now depositing; here sweeping along coarse blocks, there depositing fine silts. Ten miles south of Askhabad, where the railroad station is 819 feet altitude, we saw, when returning by the Meshed road from an excursion in the Kopet Dagh, more abundant piedmont deposits of mountain-waste dissected to depths of several hundred feet. A great thickness of these deposits has been penetrated by the artesian boring in the suburbs of Askhabad, already mentioned, 2000 feet deep, and therefore with more than half its depth below sea level, but without securing a water supply. The whole depth, as shown in the record quoted by Walther, is in variable layers of clay, sand, and gravel, similar to the deposits seen in the barrow-pits near the railroad embankments, or in the natural sections; and all of this heavy deposit is therefore best explained by conditions and processes like those of to-day during persistent depression of the surface. The failure to secure a water supply from this deep well is in itself very suggestive of the irregular underground structures and of their torrential origin."

An excursion into the Kopet Dagh and the mountains of Persia revealed abundant evidence of sub-recent terracing in the valleys of a character to suggest a relative uplift of the heart of the chain. The desert plains from Askhabad to Samarkand are characterized by aggrading rivers. "The most notable feature of this district was the absence of valleys. The rivers have channels in which their waters are usually restrained, but there were no valleys in which the river floods were limited. The plains were open to overflow as far as flood supply held out. We were told, however, that some distance upstream (to the south) the Murg-ab has a flood-plain slightly depressed beneath the plain. This we interpreted as meaning that the river had there changed its habit from aggrading to degrading. On crossing the Amu at Charjui we saw a low bluff on the north or right of its course, although on the south the plain is not significantly above the river.

"The general absence of valleys is a natural, indeed an essential, feature of a fluviatile plain in process of aggradation by flood deposits. It is peculiarly appropriate to rivers like the Tejen and Murg-ab, which dwindle away and end on the plain, so that every grain of sand and every particle of silt must be laid down as the water volume lessens and disappears. The absence of valleys would, on the other hand, be surprising in a

lacustrine or a marine plain, for the reason that coincidence could hardly be expected between the slope that might be given to such a plain when it is laid bare and the slope that is satisfactory to the graded rivers that run across it. It is not, however, as has already been pointed out, always the case that fluviatile plains have no valleys eroded beneath their general level. The river-made plains of northern India are now commonly somewhat trenched by their rivers. Our Great Plains, piedmont to the Rocky Mountains, are likewise in process of dissection by their rivers. The plains of Turkestan are therefore somewhat exceptional in this respect. As a result we had unfortunately no opportunity of seeing sections of the plains in which the structure of the deposits could be examined. A well on the Czar's estate at Bairam Ali, a modern village near Old Merv, where we were most agreeably entertained by the superintendent. Mr. Dubassof, was said to have shown nothing but 'sand and loess.' The desert and river deposits found by borings beneath the Amu River beds at Charjui have already been noted. The inspection of these vast plains of silt was very suggestive in connection with the problematic origin of the fresh-water Tertiary formations of the western United States. Certainly no one who sees the river-made area of the plains of Turkestan can doubt the capacity of rivers to lay down extensive fine-textured deposits."

In regard to the Tian Shan mountains Professor Davis states that "A number of the mountain ranges that we saw were of vigorous form, with sharp peaks and deep-carved valleys, in which it was impossible to recognize any trace of the original unsculptured mass; but certain observations made in the central and northern ranges, near Lakes Son Kul and Issik Kul, and on the steppes that border the mountains on the north, led to the belief that the region had been very generally worn down to moderate or small relief since the time of greater deformation, which probably occurred in the Mesozoic age; that large areas of subdued or extinguished mountain structures are still to be seen in the low ranges and in the steppes north of the Ili River; and that the present relief of many of the higher Tian Shan ranges is the result of a somewhat disorderly uplift and of a more or less complete dissection of dislocated parts of the worn-down region. Mr. Huntington's report shows the application of these conclusions to a large part of the central and southern Tian Shan." The space devoted to a notice of so wide ranging a report forbids further detailed mention of the numerous observations of the author upon river and glacial phenomena of the valleys of the Tian Shan.

In the article by Mr. Pumpelly, an account is given of the Kara Kul, a lake of bitter salt water, and its desert shores, and also a good description of the moraines in the mountains. Indications of two long-separated ice advances were noted and signs of a feeble third. Variations of lake level and ice advance are attributed to climatic control. Evidence is discussed

to support the supposition that in early Pleistocene time the Alai mountains wasted down until a detritus-covered piedmont plain formed on the north of the range, whereupon a dislocation seems to have occurred nearly parallel to the range and north of it with sinking of the plains still farther north or with uplift of the range. The relations of the river work to this change of altitude are briefly explained.

In his article on central Turkestan Mr. Huntington gives a summary of the geology and topographic development. Of the Paleozoic series he states: "In Central Turkestan a single succession of strata is repeated again and again, with only slight local modifications. The oldest observed formation is an ancient white marble, shot through and through with intrusions of granite. It was noticed only in the Alai Mountains in the neighborhood of Kok Su and Karategin. Its junction with the overlying formation was not seen, but the contact presumably shows an unconformity, as a conglomerate near the base of the covering strata contains pebbles of the marble. The granite which is intruded into the marble is of much later date, for it occurs abundantly in the Paleozoic series in the ridges of the Tian Shan plateau and along the north side of the Alai range. The main body of the Paleozoic series is a great thickness of limestones, many of them slaty, which are stated by Tchernachef to be of Devonian and Carboniferous age. They are greatly folded and have been penetrated not only by granite intrusions, but also by some basaltic lavas, as may be seen, for instance, in the Sugun Valley west of Shor Kul. The folding of the Paleozoic strata is of the sort which is associated with mountain building, hence at the end of the Paleozoic era or in the early part of the Mesozoic this part of Central Asia must have been highly mountainous. In evidence of this it may be pointed out that the succeeding unconformable conglomerates are so coarse that they could only have been formed subaerially in a region of considerable relief, and yet at the time of their deposition the old folds of limestone and slate had already suffered great denudation. As a rule, the hard Paleozoic strata are found in the highlands, while the softer Mesozoic and Tertiary strata occur in basins among the highlands and mountains; but this seems due less to the superior resistance of the older rocks than to the fact that they were bent down where they are covered, and that the younger strata were largely formed in the very basins which they now occupy."

"The conditions under which the Mesozoic-Tertiary series were deposited seem to have been largely subaerial, or at least nonmarine. The coarse conglomerates at the base probably indicate arid or semi-arid conditions in a region of considerable relief. As relief grew less, or as the climate grew moister, the gravel of the conglomerate gave place to sand, and that in turn to shale; in the latter are four or five coal seams. The next period, that of the vermilion beds, seems to have opened at a time of sub-

aerial deposition when the conglomerates and the cross-bedded sandstones were formed; but toward the end the encroachment of the sea is indicated by the deposition of the marls and fossiliferous limestones. Elsewhere throughout the whole Mesozoic-Tertiary series fossils seem to be wholly absent, although the deposits are well fitted to preserve the remains of plants and animals if any had existed; but here the calcareous strata, which show other evidences of being marine, contain fossils in abundance. Above the limestones the strata are at first red, as though the shallowing of the sea allowed the very highly weathered soil of an old land mass to be washed farther and farther out into the area of deposition. The succeeding formations, the pink and brown sandstone and the brown conglomerate, show a nearer and nearer approach to present conditions. It appears as though, after the retirement of the sea, the land was covered with great playas, on which water first stood in thin sheets, forming ripple-marks in the mud, and then retired or was evaporated, allowing the surface to become sun-cracked. As time went on streams began to flow across the playas, at first slow and broad and able to cut only shallow channels, which were afterwards filled and covered, assuming the form of very thin lenses of a material slightly different from that of the surrounding playa strata. Then, as the strength of the streams increased, sand was deposited over the whole area, and the channels, now deep and distinct, were filled with gravel. Lastly, gravel was deposited almost everywhere."

Central Turkestan exhibits a recently warped and elevated peneplain the dissection of which is assumed to have begun in the closing Tertiary, though the uplift is placed mainly in Pleistocene time. Summit glaciers were found among the mountains between Marghilan and Issik Kul. From his observations upon the ancient moraines of these glaciers the author concludes that: "Wherever old moraines are well developed they indicate that the glacial period is divisible into two or more subdivisions; and where the valleys are large and reach high enough still to contain glaciers the number of these subdivisions is five, marked by successive moraines, each of which is smaller and at a greater altitude than its predecessor. Two theories present themselves as worthy of consideration in explanation of these facts. According to one there was but a single glacial advance and retreat. The retreat was not accomplished uniformly or rapidly, but by successive steps, after each of which there was a long pause that gave opportunity for the accumulation of a moraine; thus five moraines were formed by each glacier and those now in process of deposition belong to the sixth step of the same long retreat. According to the other theory, each moraine represents a distinct glacial epoch, during which the glaciers first advanced and then retreated. Under this theory the intervals of retreat were as warm as or warmer than the present and the ice retreated far into the mountains during each of them.

"For fifteen out of the twenty-four glaciated valleys examined the first theory is sufficient, but it will not explain the other nine. In eight of these nine valleys one or more of the older moraines lies upon a topography different from that of to-day, so as to suggest that the moraines and the floor on which they rest have been trenched by a valley of stream erosion. In this valley lie the younger moraines, leaving the older moraines as terraces which extend beyond the later moraines both up-valley and down-valley; the up-valley extension of the morainic terrace gives a minimum measure of the retreat of the glacier during the interglacial epoch. In the ninth valley a detached portion of an older moraine lies far up-valley from its successor and even above the main part of the modern moraine. These facts are to be explained only by supposing a glacial retreat and advance in each interglacial epoch, and hence a warmer interglacial epoch between colder glacial epochs. Another sort of evidence of a warmer interglacial epoch is found where one moraine lies upon its predecessor in an attitude which indicates that before the deposition of the younger moraine the older one was first an area of erosion and later of deposition. All these facts accord with the theory of successive advances and retreats, and thus warrant the division of the glacial period into several glacial and interglacial epochs. In one place or another signs of an interglacial retreat are found between each successive pair of the four earlier moraines, while the fifth moraine stands apart from the others, except at Kan Su, where the time during which there is evidence of retreat may be either between the third and fourth or fourth and fifth advances of the ice. Everywhere the climate of the successive glacial epochs seems to have grown less severe, and the duration of the interglacial epochs seems to have diminished in the same ratio."

A succession of terraces found in the valleys are regarded as the result of a climatic change. The number of climatic swings thus inferred agrees essentially with the series of cold epochs based upon the occurrence and distribution of moraines. He states: "The essential point in our study of the recent geological history of Turkestan is this: From three separate lines of reasoning, based on the allied yet distinct phenomena of glaciation, terracing, and lake expansion, we arrive at the same conclusion, namely, that during the Quaternary era there have been a number of colder or glacial epochs, five or more, separated by warmer interglacial epochs when the climate was similar to that of to-day; and further, that these epochs progressively decreased in length and intensity."

In the final article on the basin of eastern Persia and Sistan Mr. Huntington discusses briefly the geology and in a more complete way the physiography of this desert basin. In a summary paragraph he states: "The facts set forth above, so far as they warrant any conclusion, suggest that in Eastern Persia the lower strata of the basins are generally greenish shales, which are now exposed along the edges of the basins where they have been

extensively warped and compressed. Above them occur reddish silts containing more or less sand and gypsum and warped like the underlying shales, although to a less extent. In certain places toward the top of the series the red strata alternate with green clays. Above all lie the deposits of silt and gravel which are to-day accumulating. Although these different strata show varying degrees of warping along the edges of the basins, it is noticeable that toward the centers they approach the horizontal position. It is probable that in the centers of many of the basins an uninterrupted series of strata has been deposited from the time of the post-Cretaceous uplift of the country until now. At first a shallow sea or large lakes probably occupied the central portions of Iran and allowed the deposition of the green shales. Later, as the great basin was broken into smaller basins, the larger bodies of water gave place to smaller ones, and these, under the influence of a dry climate, gave place to playas or shallow salt lakes where the prevailing deposits were reddish silts. Still the process of deepening the basins and decreasing their area went on, with the result that the green shales were more highly warped and the red deposits were also uplifted along the borders of the basin and were exposed to erosion. Meanwhile the superficial deposits which now cover the plains were laid down and the country assumed its present form. It is not to be supposed that every basin has gone through exactly the same process, or that a single process has everywhere taken place at the same time. Accidents have intervened. At Zorabad the damming of the Heri Rud formed a lake and greatly altered the course of events. At Sistan, and probably elsewhere, a series of lakes appears to have occupied the basin during the glacial period. Nevertheless the general course of events was a gradual progress from larger basins to smaller basins, and from subaqueous to subaerial deposition."

The report is well illustrated and its publication in this country cannot but help correct the too great reluctance of American geologists to depart, in their interpretation of the continental deposits of western America, from the traditional invoking of those processes which in the infancy of geology were the sole known agencies of change because they are the controlling ones in its birthplace. The English geologists in India and Persia long ago pointed out the magnitude and characteristics of the reproductive work of rivers, and of the changes going on in arid regions; and Mr. Huntington well observes that the likeness of the physical history in Central Asia and the western and southwestern portions of the United States is now and has been in the course of geological time very striking both in product and process.

J. B. W.

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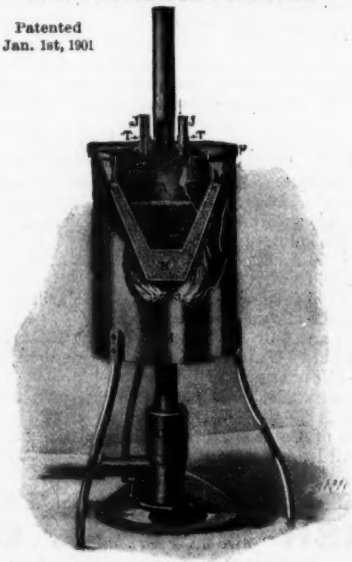

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